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THE EFFECTS OF SYSTEM AND ENVIRONMENTAL FACTORS UPON EXPERIENCED PILOT PERFORMANCE IN THE ADVANCED SIMULATOR FOR PILOT TRAINING

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The objectives of the study were: (a) to assess the relative contribution of platform motion, G-seat and visual factors to pilot performance in the Advanced Simulator for Pilot Training (ASPT), (b) to acquire information on the relationships between system output and pilot input measures as collected in the ASPT, and (c) to evaluate the utility of economical multifactor designs for Flying Training Division, Air Force Human Resources Laboratory (AFHRL/FT) research in flight simulation. Three experienced T-37 pilots flew five maneuvers in the ASPT under combinations of the independent variables platform motion, G-seat, field of view, turbulence, wind and ceiling/visibility. Automated performance measures based on system parameters, pilot inputs and derived scores were collected and analyzed. Both main and interactive effects of the independent variables were found for a majority of the maneuvers. A discussion of the utility of the economical multifactor designs is included. Additionally, implications for determining the direction of future studies are discussed.

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PREFACE

This effort was conducted by the Flying Training Division of the Air Force Human Resources Laboratory, Williams Air Force Base, Arizona 85224, and supported by the 82nd Flight Training Wing, Williams Air Force Base, Arizona. The project was completed under 1123, United States Air Force Flying Training Development; task 112303, the Exploitation of Simulation in Flying Training; and work unit 1123-03-18, Simulation Design Configurations Study I (Motion, G-Seat, Visual). Dr. William V. Hagin was the project scientist and Mr. Jim Smith was the task scientist. The authors would like to extend special thanks to Capt Thomas Beil, Capt James Gormley, and Capt Louis Lake, for their dedication as subjects for the duration of the study. The report covers research performed between May 1975 and October 1976.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

THE EFFECTS OF SYSTEM AND ENVIRONMENTAL FACTORS UPON EXPERIENCED PILOT PERFORMANCE IN THE ADVANCED SIMULATOR FOR PILOT TRAINING

I. INTRODUCTION

Problem Statement and Study Rationale

Three primary sources of cues used for aircraft control are provided to the pilot by cockpit instrumentation, the external visual scene, and vehicle motion. Because pilot performance is fundamentally dependent upon information originating from these sources, modeling these aspects of the environment has been considered of vital importance in the design of flight simulators. Although satisfying simulator motion and visual requirements is difficult, the situation is further complicated by possible interaction effects that may occur between them. The present study is a preliminary investigation of these phenomena and their effects upon experienced pilot performance.

An aircraft in flight has unlimited freedom of rotational and transitional movement around three axes. Rotational movement consists of roll, pitch, and yaw, and translational movement is comprise of lateral, longitudinal and vertical displacements. State-of-the-art motion simulation devices (e.g., motion platforms, G-seats and G-suits; individually and in combination) can generate movements in these dimensions to various levels of fidelity.

Visual scene generation also has a variety of state-of-the-art systems which have been utilized to increase the fidelity of aircraft simulators (e.g., computer image generation, model board, and calligraphic displays). The fidelity of visual simulation may be enhanced by: (a) increasing the field of view (FOV), (b) expanding the edge generation capacity in computer image generation systems, or (c) increasing the resolution and the FOV of camera probes used with model boards. Thus, the fidelity of the outside-the-cockpit visual scene, as well as the fidelity of kinesthetic cueing mechanisms, must be selected based upon decisions on which essential cues are required by the pilot and in what manner they should be presented.

Considering the extensive future use of flight simulation projected by the Air Force, information on simulator design requirements is urgently needed. To accomplish this task, ideally, a large factorial study could be conducted that simultaneously addressed all facets of the problem. Such an approach is impractical, and an alternative strategy must be adopted. This study was the first of a series developed according to this strategy, and was intended to provide a "first look" at certain major variables of motion, the visual scene, and their interactions. The experiment was limited to what could be reasonably accomplished in light of subject availability, equipment capability, and software support development at the time of the study.

Study Objectives

The purposes of the study were:

First, to assess the relative contribution of platform motion, G-seat, and visual factors to pilot performance under systematically varied environmental conditions. The results of this evaluation should begin to define the variables and levels of variables to be utilized in follow-on studies in this series.

Second, to acquire information on the relationships between system output measures and pilot input measures as measured in the Advanced Simulator for Pilot Training (ASPT) when flown under specified tasks, environmental conditions, and simulator configurations.

Third, to evaluate the utility of economical multifactor designs to Air Force Human Resources Laboratory, Flying Training Division (AFHRL/FT) investigations into the contributions of motion and visual factors upon pilot performance in flight simulators.

Background

Historically, the art of aircraft simulation has had as one of its foremost goals the development of a maximum fidelity device which could provide realistic cues matching those present in the aircraft. Currently, the major areas of concern lie in motion and visual cue generation.

Movement and/or tactile pressure is a necessary condition for motion cueing. One recent technical approach for providing realistic sensory information has resulted in the creation of pneumatically-driven seats (e.g., G-seat, dyna-seat). Air-driven bladders (located on the seat and back rest) inflate or deflate to provide the "seat of the pants" cues which are normally experienced in

flight (Bell, 1974). Research pertaining to these newly developed "G-seat" devices has been understandably limited due to the small number which have been installed for use on sophisticated simulators. In one study on G-seat cueing, however, performed by Taylor and Gerber (1969), it was reported that improvements in pilot training resulted when "G-seat forces" were provided in conjunction with motion cueing.

Kinesthetic and vestibular cueing are also provided by the use of complex platform motion systems. Probably the most recent and most commonly used are the synergistic six degree of freedom (DOF) systems of various excursion lengths. In the area of platform motion simulation, research has been prolific. Numerous investigations have been directed towards determining which DOF are required for motion systems in particular settings as well as what levels of fidelity are needed (Bergeron, 1970; Jacobs, Williges, & Roscoe, 1973). This body of research, however, is equivocal, and findings have often not been consistent from study to study.

Much of the research to date has shown that simulator motion produces improved pilot performance in controlling the simulator (Borlace, 1967; Brown, Johnson, & Mungall, 1960). Additionally, Rathert, Creer, and Sadoff (1961) demonstrated that varying the fidelity of motion cueing correspondingly improved the pilot's performance in the simulator. Koonce (1974) investigated the effectiveness of platform motion using three conditions of motion cueing (i.e., no motion, sustained motion cueing, and washout motion cueing). This study also showed an increase in pilot performance in the simulator when motion cueing was present.

The evidence supporting the positive effects of high fidelity motion platforms is not unchallenged. Demaree, Norman, and Matheny (1965) concluded that in many instances the level of motion fidelity could be reduced without any appreciable performance decrement on tracking tasks. Huddleston (1966) reported that motion may not be necessary for those tasks performed in the more stable flight regimes, although it may be beneficial in highly dynamic regimes Finally, the study conducted by Jacobs and Roscoe (1975) highlighted a vital issue Roscoe found that pilot performance, in terms of errors committed, improved in the simulator with the presence of a type of motion, either *normal* washout or *random* washout. The critical point was that the random washout condition provided essentially appropriate onset cueing, but random directional cueing.

Recent development in visual system technology have dramatically increased the amount and quality of visual information displayed to the pilot. One important aspect of visual dispalys that has received considerable research is the FOV required to successfully perform certain tasks in the simulator. Roscoe (1951) ascertained that pilots were able to land safely with a very limited FOV (± 10° horizontal and vertical). However, he also concluded that increasing the FOV improved pilot performance on the landing task. Armstrong (1970) examined landing performance of military pilots under a restricted (± 25°) horizontal display, vertical FOV being unlimited, and discovered that pilot performance was nearly unchanged with this loss in peripheral vision cueing. Reeder and Kolnick (1964) reported similar results. Wolff (1971), using these findings, suggested that a 60° horizontal display was usually adequate for most piloting tasks requiring visual cueing.

The majority of research on the interactive effects of motion and visual cues deals with visually induced motion (Young, Dichgans, Murphy, & Brandt, 1973; Young, Oman, Curry, & Dichgans, 1973). Associated with this phenomenon is the problem of disorientation and simulator sickness thought to be caused by conflicting cues; i.e., a moving visual display accompanied by a stationary cockpit. Although such psychophysiological effects have been studied rather extensively, there is a lack of information relating to the relative contributions of the interactions of various visual displays and motion configurations to pilot performance.

It should be noted that the research findings reviewed are extremely subject, task, and vehicle specific. For example, the visual/motion cues required to simulate an air combat engagement in an F-15 aircraft undoubtl differ greatly from those required for a straight-in approach and landing in a T-37 aircraft. Further, these studies were concerned with pilot performance in the simulator, which may or may not be related to the training effectiveness of the simulators. Considerations of this type usually place stringent limitations on the generalizations that may be made from a study. The present study is no exception to this rule, and its findings are subject to the same *caveats*.

II. METHOD

A rather complex experiment was required in order to achieve the purposes of the study. This

resulted because the first and third objectives (i.e., investigation of multifactor expeimental space and use of a highly economical design) were difficult to combine in one package. The design that satisfied these objectives became the driving element that determined the methods and procedures.

Subjects

Three experienced pilots were selected as subjects in order to remove the confounding effect of learning from the performance scores. The subjects were T-37 instructor pilots (IP) at Williams Air Force Base, Arizona, whose flying time ranged from 550 to 900 hours.

Apparatus

The ASPT located at AFHRL/FT was used for the duration of the study.

The following description of ASPT briefly delineates those capabilities of ASPT used in this experiment. In-depth technical references are found in Bell (1974); Hagin and Smith (1974); and Rust (1975).

ASPT has two fully instrumented T-37 cockpits mounted upon six DOF motion platforms. The synergistic motion system has six active drive legs with approximately three feet of vertical travel and four feet of horizontal travel. Displacement capabilities include: pitch –20 degrees to +30 degrees; roll ±22 degrees; and yaw ±32 degrees. These displacements are intended to provide initial (on-set) cues for all maneuvers. The 31-bellow pneumatic G-seat in ASPT is designed to provide more continuous cues than the motion platform and accomplishes this by the orderly inflation and deflation of the bellows in response to the requirements of each particular maneuver.

The visual system of ASPT is comprised of seven 36-inch monochromatic cathode ray tubes (CRT) placed around the cockpit giving the pilot +110 degrees to –40-degrees vertical cueing and ±150 degrees of horizontal cueing. The computer generated visual scene has the capability to display information for most pertinent ground references (mountains, runways, hangars, etc.) within a 100 square nautical mile area of Williams AFB. As the T-37 moves through this environment, the visual imagery is updated 30 times per second such that the presentations are similar to what a pilot would see in the real world.

Automated performance measures are collected and stored at an iteration rate of 3.75 to 15 times per second

The computer system also possesses a Cognitronics voice capability for ground-controlled approaches (GCA). All systems of ASPT (motion, visual, etc.) can be degraded to match a wide variety of environmental conditions or aerodynamic characteristics.

Design

One of the principal considerations of any projected research is that of economy of resources. There are practical limitations to the number of individuals chosen to participate, the number of observations selected, the amount of time available to gather the information, and most critically, the expenses incurred. Generally, two approaches have been used to circumvent this problem: methodically developing a research strategy; or statistically controlling the experimental design. Under the second approach, countless methods have been developed to achieve economy in the collection and analysis of information ranging from the traditional one-way analysis of variance to the fairly recent response surface designs. Simon (1973) has written extensively on the use of screening studies for achieving a maximum amount of information with a minimum expenditure of effort in terms of time, sample size, and equipment usage. Simon proposed the use of multilevel, multivariable designs whereby analysis provides an economical "map" of the significant experimental space. This "map" is then used to guide more thorough research in the area. The design used in this study followed the "mapping" approach.

Two separate experimental designs were utilized. The first design, structured to evaluate main, first-order interaction and second-order interaction effects of all six independent variables was configured as a 3^3 2^3 randomized block partially confounded factorial.

The six independent variables, three with two levels each (ceiling/visibility, field of view, G-seat) and three with three levels each (winds, turbulence, motion), generated 216 unique treatment combinations. Using randomization, each of the three subjects was assigned a block of 72 treatment combinations under which they flew takeoffs, GCAs, and 360 degree overhead patterns Each of the three pilots flew one-third of all possible treatment combinations, reducing total cell numbers from 216 to 72 per subject

The second design, a 3^4 randomized block partially confounded factorial, used four independent variables (turbulence, motion, field of view, G-seat) each with three levels which generated 81 unique treatment combinations. Field of view (FOV) and G-seat were modified from their two-level configuration in the 3^3 2^3 design to three-level variables in the 3^4 design. Each of the three subjects flew aileron rolls and slow flights under 27 of the 81 conditions.

In both designs, the confounding occurred in the third order and higher order interactions. These interactions were hypothesized to contribute little to the experimental variance and were thus deemed to be of slight interest. To increase statistical power, these confounded interactions were added into the error terms.

Independent Variables

Six independent variables (IV) were employed in the first design. These were selected so that the subjects performed the designated maneuvers across a wide variety of environmental conditions and simulator configurations.

Three IVs (wind, turbulence, and eiling/visibility) dealt with environmental conditions. Three levels of the wind variable were selected: zero, 12, or 24 knots all generated from 60 degrees left of the runway centerline. The turbulence variable was composed of no turbulence, light, or moderate turbulence conditions. The ceiling/visibility (C/V) variable had two levels: clear and minimums. The minimums were defined as 200 feet ceiling and ½ mile visibility (200 feet/½ mile) for the GCA maneuver and 1200 feet/3 miles for the 360 degree overhead pattern maneuver, and represented real-world minimum allowable conditions for those maneuvers. These three IVs yielded 18 unique environmental conditions ranging from no wind, no turbulence, and clear C/V to 24 knots crosswind, moderate turbulence, and clear C/V to 24 knots crosswind, moderate turbulence and minimum C/V.

Three IVs dealt with the configuration of ASPT. Zero, three and six DOF levels were selected for the motion variable. The three DOF condition included motion only in pitch, roll, and heave (vertical translation) dimensions. The six DOF condition consisted of motion in pitch, roll, yaw, longitudinal, vertical, and lateral displacement. The FOV variable had two conditions: masked and full. The full condition utilized all seven cathode ray tube (CRT) channels. The masked FOV, designed to represent the FOV of many small visual displays currently in use, had a 36-degree vertical and 48-degree horizontal FOV. The 36 degree by 48 degree masked FOV was created by shutting down five of the seven CRTs and placing a portable black cardboard mask over portions of the two remaining CRTs to reduce the FOV to 36 degrees by 48 degrees. The G-seat variable possessed two levels: functional or non-functional.

The combination of environmental and ASPT configuration IVs (18x12) produced 216 unique treatment cells.

The second design used four IVs, each having three levels (3^4). Two of the four variables used in this design, motion and turbulence, were configured exactly as above. The third variable, FOV, had masked and full FOVs as in the first design, but added a third level in which there was no visual scene present in order to simulate a completely instrument flight rules (IFR) condition. The fourth variable, G-seat, similarly was either functional or non-functional as in the first design, but added a third level which directed that only the G-seat's pan was functional. The Seat Pan Only configuration made use of only those pneumatic panels located in the area of the pilot's buttocks in order to estimate the separate contributions of these panels.

These combinations of environmental and ASPT configuration IVs produced 81 unique treatment cells.

Flight Tasks

In this study, the term "flight tasks" refers to the five specific maneuvers flown by the subjects. These maneuvers were selected to encompass a broad spectrum of representative subtasks in the undergraduate pilot training (UPT) curriculum (Meyer, Laveson, Weissman, & Eddowes, 1974).

In the first design, each subject flew 72 take-offs, 72 GCAs, and 72 360-degree overhead patterns for a total of 216 maneuvers (under the varying environmental/system configurations) per subject. In the second portion of the experiment, each subject flew 27 aileron rolls and 27 slow flights for a total of 54 maneuvers (under the various configurations) per subject.

Dependent Variables

The dependent variables used in this study were derived from the ASPT Automated Performance

Measurement System (APMS). The APMS is basically a criterion-referenced approach to measurement. Because most skillful piloting involves the attempt to maintain or change to specified flight parameter criteria (e.g., airspeed, altitude, vertical velocity), deviations from these desired parameters provides a method of quantitative objective performance measurement.

For this study, sets of dependent variables believed to be of relevance were selected independently for each maneuver and were recorded via the APMS at an iteration rate between 3.75 and 15 times per second. The variables monitored are listed in Appendix A. These dependent variables were classified into three categories: (a) system output measures, (b) pilot input measures, and (c) derived measures.

System output measures were used to measure deviations from desired criteria via root mean square techniques (Waag, Eddowes, & Fuller, 1974), which have been demonstrated to be reliable descriminators of pilot performance.

Pilot input measures were computed to determine an analog to how much effort or work was expended by the pilot on the aircraft controls during the maneuver. It has been generally accepted that pilots with more experience make fewer, more precise correctional movements than relatively inexperienced pilots. This analog was measured for aileron, elevator, and rudder control. This analog of pilot effort was computed as work per unit of time and was expressed by the following equation:

$$\text{Pilot Input} = r/n \sum_{i=i}^{n} |P_i - P_{i-1}| \times \frac{|f_i + f_{i-1}|}{2}$$

where r is the sampling rate, n is total number of samples, P is control position, and f is control force.

The derived measures were a set of measures that produce a single composite score for a particular segment of a maneuver or a complete maneuver. For the most part, this score was based on the pilot's proficiency in simultaneously staying within several tolerance bands constructed around the desired criteria. The score was a percent-time-within-tolerance measure. Tolerance bands were constructed using the performance of experienced pilots for each maneuver or maneuver segment as a basis.

This approach to performance measurement was implemented through use of the ASPT Preprogramming System. This system permitted generation of FORTRAN programs, called exercise segments, which used simulator flight variables as input data. (For a complete description of the five exercise segments, see Appendix A).

Table 1 lists all dependent variables by maneuver. Because system measures used deviation scores, a smaller score indicated better performance. Similarly, on pilot input scores, smaller forces applied by the pilot to remain within the established tolerances produced smaller scores, indicative of better performance. The derived measures, however, were based on percent-time-within-tolerance scale with 100% being defined as remaining within the given tolerance bands for the entire duration of observation. Thus, higher percentages indicate better scores.

Procedures

The procedures used in the study can conveniently be separated into two classes: subject pretraining, and data collection procedures.

1. *Subject pretraining*. Each subject was given approximately 3.5 hours in ASPT for the purpose of familiarization and warmup one to two days before the start of the study. During this time, two separate mission profiles with varying environmental conditions were briefed to and practiced by the subjects.

PROFILE I (3^3 2^3 Design Maneuvers)

a. Takeoff and climb on course (begun at takeoff clearance).
b. GCA (begun at five miles from touchdown gate).
c. VFR "overhead" traffic pattern (begun on initial).

PROFILE II (3^4 Design Maneuvers)

a. Slow flight (initialized at 100 kts, 12 K ft).
b. Aileron roll (initialized at 160 kts, 15K ft).

2. *Data Collection Procedures*. In the course of the study, each subject flew Profile I 72 times and Profile II 27 times as required by the experimental design. On the average, Profile I required 19 minutes for completion and Profile II required 6 minutes. The two profiles were randomly ordered for all subjects. The mission profiles were

Table 1. **Dependent Variable Listing**

	Dependent Variable Name	Type	Units
	Takeoff and Climb on Course		
1.	Heading Deviation	System	Degrees
2.	Pitch Deviation	System	Degrees
3.	Course Deviation	System	Degrees
4.	Airspeed Deviation	System	Knots
5.	Elevator Power	Pilot	lbs-deg/sec
6.	Aileron Power	Pilot	lbs-deg/sec
7.	Rudder Power	Pilot	lbs-deg/sec
	GCA and Landing		
1.	Total Score	Derived	Percent
2.	Touchdown Score	Derived	Percent
3.	Altitude Deviation	System	Feet
4.	Airspeed Deviation	System	Knots
5.	Centerline Deviation	System	Feet
6.	Glidepath Deviation	System	Feet
7.	Elevator Power	Pilot	lbs-deg/sec
8.	Aileron Power	Pilot	lbs-deg/sec
9.	Rudder Power	Pilot	lbs-deg/sec
10.	Elevator Power	Pilot	lbs-deg/sec
11.	Aileron Power	Pilot	lbs-deg/sec
12.	Rudder Power	Pilot	lbs-deg/sec
	360° Overhead Pattern and Landing		
1.	Pitchout Altitude	System	Feet
2.	Pitchout Bank	System	Degrees
[illegible]	Elevator Power	Pilots	lbs-deg/sec
4.	Aileron Power	Pilot	lbs-deg/sec
5.	Rudder Power	Pilot	lbs-deg/sec
6.	Downwind Altitude Deviation	System	Feet
7	Downwind Score	Derived	Percent
8.	Elevator Power	Pilot	lbs-deg/sec
9.	Aileron Power	Pilot	lbs-deg/sec
10.	Rudder Power	Pilot	lbs-deg/sec
11.	Final Turn Bank Deviation	System	Degrees
12.	Final Turn Airspeed Deviation	System	Knots
13.	Elevator Power	Pilot	lbs-deg/sec
14.	Aileron Power	Pilot	lbs-deg/sec
15	Rudder Power	Pilot	lbs-deg/sec
16.	Glidepath Deviation	System	Feet
17.	Centerline Deviation	System	Feet
18.	Final Airspeed Deviation	System	Knots
19.	Final Score	Derived	Percent
20.	Elevator Power	Pilot	lbs-deg/sec
21.	Aileron Power	Pilot	lbs-deg/sec
22.	Rudder Power	Pilot	lbs-deg/sec
23.	Landing Score	Derived	Percent
	Slow Flight		
1	Altitude Deviation	System	Feet
2.	Airspeed Deviation	System	Knots
3.	Slip Indicator Deviation	System	Degrees
4.	Total Score	Derived	Percent.
5.	Elevator Power	Pilot	lbs-deg/sec
6.	Aileron Power	Pilot	lbs-deg/sec
7.	Rudder Power	Pilot	lbs-deg/sec
	Aileron Roll		
1	Bank in Deviation	System	Degrees
2	Roll Acceleration	System	Degrees/Sec^2
3.	Roll Score	Derived	Percent
4.	Bank Out Deviation	System	Degrees
5	Aileron Power (In)	Pilot	lbs-deg/sec
6.	Aileron Power (Roll)	Pilot	lbs-deg/sec
7.	Aileron Power (Out)	Pilot	lbs-deg/sec
8.	Total Score	Derived	Percent

flown consecutively within a data collection period, which varied from one to two hours in length dependent upon ASPT system availability. Rest periods were provided whenever requested by the subject IPs.

After the pilot strapped into the cockpit, each session was begun with instructions provided by the Cognitronics computer-driven word generator. During strap-in, the console operator entered identification information into the APMS files, modified the simulator configuration, and set the environmental factors. Each maneuver was begun on command and completed when selected criteria were satisfied; i.e., the takeoff and climb on course was terminated when the altitude equalled 3,000 feet mean sea level (MSL). An aural tone signified termination of the maneuver. In the case of the GCA, the Cognitronics generator provided all verbal information to the subject, including glide-slope and centerline deviations. At the completion of each maneuver within the profile, the console operator entered comments on any system malfunctions, operator or subject error experienced during the maneuver.

All profiles were flown in cockpit A of the ASPT to control for possible inter-cockpit differences.

In setting up those treatment conditions which required the motion system to be inoperative, the console operator initially raised the platform and then froze it in an attempt to preclude subject awareness of the simulator configuration. During the course of the study, however, the subjects became "experiment wise" and were often able to discern the exact configuration.

Prior to the execution of each maneuver, all environmental conditions, (i.e., ceiling/visibility, winds, turbulence) were given to the pilots as they would be in the real-world of flying.

Due to a hardware configuration error in the method of setting the particular G-seat configuration, each IP had to refly 18 profiles, resulting in a total of 117 profiles flown per subject.

The major constraint in subject scheduling was ASPT system availability. Subjects were scheduled on a day-to-day basis. Data collection began on 25 June 75 and was terminated on 30 October 75. System reliability during the conduct of the study was approximately 62 percent, as measured by the following ratio: hours of successful data collection/hours scheduled for the effort.

Analysis

The analysis presented in this technical report differs significantly from that given in a previous one (Waters, Grunzke, Irish, & Fuller, 1976). The earlier report was based on a univariate analysis of each dependent variable. The present report utilized a multivariate approach.

In recognition of the intercorrelations between the dependent variables of each specific maneuver measurement set (Waters et al., 1976), a multivariate analysis of variance (MANOVA) was selected as the appropriate omnibus test (Harris, 1975). A MANOVA was performed for each maneuver which resulted in five overall tests of significance. The statistic used in determining significance of effects was the Wilks Lambda (λ). The Wilks Lambda statistic, while not only being less difficult to compute than the greatest characteristic root (GCR) method, also provided a more powerful test than the latter (with the assumption of nearly equivalent characteristic roots). Upon reaching significance, traditional step-down univariate F's were computed for each dependent variable. Means and exact probability levels $p(F > F_0)$ were also computed for each dependent measure. The alpha level for this study was set at .05.

Additional multivariate post hoc tests were not pursued for two reasons. First, the Wilks Lambda does not lend itself to further multivariate contrasts; and second, the sample size employed was not sufficient for extensive multivariate comparison using a multiple discriminant or principal components analysis.

Although the step-down F's are subject to similar inflation of the Type I error rate as are a series of conventional univariate ANOVAs (Harris, 1975), a screening study of this type would prefer minor inflation in Type I rather than Type II error rates in order that all possible sources of variance may be identified for future studies. Additionally, percent of non-error variances (% NEV) were computed for each source of variance so that the relative importance of each effect could be estimated.

The matrices used to construct the MANOVA tables were structured such that all main effects, first order interaction effects and second order interaction effects were orthogonal to one another in the $3^3\ 2^3$ design with the exception of the Wind by Turbulence by Motion interaction which had

two of its degrees of freedom confounded with between block variation. All third order and higher interactions were assumed to be negligible. The 3^4 design was structured so that all main effects and first order interactions were orthogonal, with second order and higher order interactions assumed to be zero.

The final statistical procedure performed upon the data consisted of rank ordering the performance of each dependent measure for those interactions of statistical significance. Because the dependent variables varied greatly in the nature of their units and the direction of best performance in terms of their absolute values, a procedure was required which accounted for these differences. The selected method included the rank ordering of performance on the dependent measures from best to worst performance within every treatment cell of the interaction. The ranks were then summed across all dependent measures for each cell and an average rank was determined. Nemenyis' test (Kirk, 1968) was employed to determine the location of significant differences between the average ratings in the treatment cells. This method allowed the dependent measures to be summed into an unweighted linear combination, thus providing insight into the relative strength and direction of the performance measurement sets within each interaction. Since it was impossible to empirically determine what the individual variable weights should have been, this procedure used *equivalent* weights for all variables. Although this method varied somewhat from a more traditional approach, it offered a straight-forward and relatively economical method of describing the underlying processes at work within each interaction.

III. RESULTS

Because of the sizeable quantity of information this study produced, the results section is structured in the following manner. Initially reported are the main effects which reached significance. These effects are classified into two categories: environmental variables, and system configuration variables. Presentation of the significant first order interactions follows; these were subdivided into three major classes. These classes are: interactions of environmental variables with environmental variables, interactions of system variables with environmental variables, and system variable by system variable interactions. Finally, the one second-order (three variable) interaction which reached significance was reported. This scheme was followed in reporting the results of the 3^3 2^3 design, and then repeated for the 3^4 design.[1]

3^3 2^3 Environmental Variables

Wind. The first environmental main effect considered was the wind factor. The wind main effect, as expected, evidenced consistent linear effects. As wind velocity increased, flying performance decreased. Table 2 depicts the means, univariate F's and the Wilks Lambda for the wind matrix for the takeoff, GCA, and overhead pattern maneuvers.

The wind effect was significant in the omnibus multivariate test across each of the three maneuvers measures ($p<.001$). The direction of significance as indicated by the tabled means shows that under increasingly windy conditions, deviations from the desired course were greater and that more subject effort was needed to fly the simulator.

For the univariate analyses, of the seven variables in the matrix for the takeoff maneuver, three (heading deviation, aileron power and rudder power) were significant at the univariate level ($p<.001$) and had relatively consistent effects; i.e., increased wind intensity produced more course deviation and effort.

The GCA landing task showed five dependent variables with significant univariate F ratios ($p < .001$). Four of these measures (rudder power (final), aileron power, elevator power, rudder power (landing)) were pilot input measures and one derived measure (touchdown score) demonstrated linear effects. Of the remaining three variables (rudder power (2), and aileron power) curvilinear effects were manifested. The last measure, elevator power (landing phase) showed best performance, assuming that fewer and smaller corrections indicated better flying, under the maximum wind condition followed by no wind and lastly 12 knots of wind. This was likely a maneuver-specific artifact due to its inconsistency with all of the other measures.

In the overhead pattern maneuver, 12 of 23 dependent variables were significant at $p<.05$ in the univariate analysis. These 12 dependent variables included four system output dependent

[1] The disparity between the multivariate and univariate source tables for the main and interaction effects stems from the method in which the DOF have been partitioned in the two analyses. Both analyses are correct, however, the univariate tests give a more conservative, more powerful test of significance.

Table 2. Wind Main Effects Across Takeoff, GCA, and Overhead Pattern Maneuvers

Source	$\bar{\bar{X}}$(0 Knots)	$\bar{X}$(12 Knots)	$\bar{X}$(24 Knots)	SSBET	SSW/IN	F	P
Takeoff							
Heading Deviation	2.10	2.66	5.39	448	225	2.11	.000*
Pitch Deviation	1.71	1.89	1.89	1.57	115	1.45	.236
Course Deviation	.926	1.10	1.30	5.05	216	2.49	.086
Airspeed Deviation	5.55	4.66	5.01	29.0	3550	.871	.420
Elevator Power	2.45	2.54	2.67	1.63	113	1.53	.219
Aileron Power	.606	.766	.977	5.00	53.5	9.94	.000*
Rudder Power	.279	.468	.519	2.42	23.3	11.07	.000*
Wilks Lambda			df_1	df_2		$p(F>F_0)$	
.278			14	414		.000*	
GCA							
Total Score	25.7	23.5	25.1	182	26100	.744	.476
Touchdown Score	87.3	84.2	79.2	2400	28700	8.89	.000*
Altitude Deviation	40.9	39.8	38.1	289	91700	.335	.715
Airspeed Deviation	2.44	2.47	2.86	8.10	350	2.46	.087
Centerline Deviation	96.0	103	106	3900	28200	1.47	.232
Glidepath Deviation	38.4	35.9	33.6	837	42600	2.09	.126
Elevator Power	.436	.463	.447	.027	12.3	.231	.794
Aileron Power	.419	.516	.457	.350	.300	1.24	.291
Rudder Power	.067	.098	.168	.397	4.76	8.87	.000*
Elevator Power	4.28	4.91	3.40	83.1	1300	6.82	.001*
Aileron Power	1.04	2.03	1.96	44.0	363	12.9	.000*
Rudder Power	1.72	5.89	17.0	8960	9120	104	.000*
Wilks Lambda			df_1	df_2		$p(F>F_0)$	
.349			24	404		.000*	
Overhead Pattern							
Pitchout Altitude Deviation	40.8	41.7	42.8	145	172,000	.090	.914
Pitchout Bank Deviation	6.25	10.9	14.9	2680	4,090	69.9	.000*
Elevator Power	2.46	1.81	1.40	41.4	324	13.6	.000*
Aileron Power	.688	.537	.393	3.13	39.7	8.41	.000*
Rudder Power	.049	.078	.089	.064	9.74	.698	.499
Downwind Alt Dev	42.3	36.2	42.0	1710	122,000	1.49	.227
Downwind Score	66.8	71.2	62.0	3060	134,000	2.43	.090
Elevator Power	2.24	2.10	1.91	3.86	301	1.36	.258
Aileron Power	1.31	1.23	1.11	1.51	220	.732	.482
Rudder Power	.106	.101	.093	.006	7.06	.094	.910
Final Turn Bank Dev	9.55	10.9	11.2	109	5130	2.25	.107
Final Turn Airspeed Deviation	4.42	4.58	8.51	772	2370	34.6	.000*
Elevation Power	1.22	1.59	2.08	26.7	251	11.3	.000*
Aileron Power	.739	.751	.932	1.67	51.9	3.43	.034*
Rudder Power	.287	.378	.600	3.73	116	3.43	.034*
Glidepath Deviation	.875	1.28	1.30	8.25	285	3.08	.047*
Centerline Deviation	92.4	159	155	170,000	1,350,000	1.33	.264
Final Airspeed Deviation	3.79	3.92	6.69	388	3020	13.7	.000*
Final Score	12.2	15.1	3.50	5270	73,600	7.63	.000*
Elevator Power	2.71	3.07	3.29	12.5	548	2.42	.091
Aileron Power	1.29	1.81	2.76	80.8	276	31.2	.000*
Rudder Power	1.16	4.07	6.74	1120	2060	58.2	.000*
Landing Score	77.4	76.2	75.9	85.9	23,700	.385	.680
Wilks Lambda		df_1		df_2		$p(F>F_0)$	
.224		46		382		.000*	

Note. — All univariate F-ratios evaluated at $F_{2,213}$.
* $p < .05$.

variables, seven pilot input dependent variables, and one derived dependent measure. Of these variables which exceeded the significance criterion, three (elevator power (pitchout), aileron power (pitchout), and final score) indicated better performance under increased wind conditions. The final score measure demonstrated slightly curvilinear effects by showing best performance in the 12 knot condition, slightly deteriorated performance with no wind followed by a marked decrease in performance in the 24 knot condition. The remaining nine dependent variables indicated decreased performance as a function of increased wind conditions.

Turbulence. The analyses of the second environmental variable, turbulence, are presented in Table 3.

The turbulence variable demonstrated an overall multivariate effect only on the GCA landing maneuver ($p<.001$).

In the univariate analysis, the takeoff maneuver produced one dependent variable (elevator power) that reached significance. This measure manifested a clear linear effect; i.e., best performance was recorded under no turbulence followed in sequence by light and moderate turbulence. Rudder power was the only dependent measure to achieve significance in the overhead pattern univariate analysis.

Ceiling/Visibility. The analyses of the final environmental variable, ceiling/visibility, are listed in Table 4 for the takeoff, GCA, and overhead pattern maneuvers.

As Table 4 shows, all three maneuvers had significant multivariate ceiling/visibility main effects ($p<.03$).

Under the univariate analysis, all dependent variables for the takeoff, excluding rudder power, had means in the expected direction (i.e., with restricted visibility conditions (minimums) performance deteriorated). The effects of reduced ceiling/visibility were particularly apparent on variables related to heading, airspeed, and amount of elevator power used ($p<.05$).

The GCA maneuver analysis has similar but not quite as powerful results. Of the 12 variables measured, six variables (two significant) suggested improved performance in the clear conditions while three variables demonstrated virtually no change under either condition. The remaining three variables suggested superior performance in the minimums condition. Nevertheless, the overall multivariate test, as previously mentioned, indicated improved subject performance in the same direction as the majority of the individual dependent variables.

Ten of the twenty-three measures used in the analysis of the overhead pattern, reached significance in the ceiling/visibility univariate contrasts. All ten measures demonstrated superior performance was evidenced under the clear C/V condition. These measures cover the full range of system output, pilot input and derived scores.

3.2.3 System Variables

The system variables consisted of platform motion, field of view, and G-seat.

Motion. The results of the analyses of the first variable of interest, platform motion, are displayed in Table 5.

Significance was reached on the multivariate test for all three maneuvers ($p<.001$).

In the takeoff maneuver, the univariate analysis of four of the seven dependent measures (three of which were system output measures) indicated superior performance in the absence of motion; however, review of the three DOF and six DOF motion conditions gave highly inconsistent results, thereby negating the establishment of a performance hierarchy.

The GCA maneuver showed a more consistent pattern of results. Of the 12 dependent variables measured in the GCA, eight measures (five significant) demonstrated superior performance in the absence of motion. The remaining dependent measures indicated superior performance under the three DOF when compared to the six DOF motion condition.

Similarly, the overhead pattern evidenced performance trends consisting of improved performance without motion followed by inferior performance with three DOF and six DOF motion.

Field of View. The analysis of the FOV main effect is listed in Table 6 for the takeoff, GCA, and overhead pattern maneuvers.

As shown in Table 6, none of the multivariate omnibus tests were significant at $p<.05$.

In the univariate analysis, the variables measured in the takeoff maneuver consistently pointed towards better performance under the full FOV. A majority of the dependent measures in the GCA, also suggested improved performance under the full FOV although less strongly than did the takeoff maneuver. The overhead pattern produced

Table 3. **Turbulence Main Effects Across Takeoff, GCA, and Overhead Pattern Maneuvers**

Source	$\bar{X}$ (None)	$\bar{X}$ (Light)	$\bar{X}$ (Moderate)	SSBET	SSW/IN	F	p
Takeoff							
Heading Deviation	3.32	3.46	3.39	.710	672	.112	.894
Pitch Deviation	1.92	1.86	1.71	1.61	115	1.49	.226
Course Deviation	1.01	1.24	1.08	2.11	.219	1.03	.361
Airspeed Deviation	4.81	5.06	5.34	10.2	3570	.305	.737
Elevator Power	2.39	2.60	2.67	3.19	112	3.05	.050*
Aileron Power	.698	.816	.836	.795	57.8	1.47	.233
Rudder Power	.374	.402	.485	.484	25.2	2.04	.132
Wilks Lambda	df_1			df_2	$p(F>F_0)$		
.922	14			414	.2576		
GCA							
Total Score	26.5	22.7	25.1	506	25,800	2.09	.126
Touchdown Score	82.5	82.6	85.7	503	30,600	1.75	.177
Altitude Deviation	34.6	40.3	43.9	3,170	88,800	3.80	.024*
Airspeed Deviation	2.02	2.62	3.13	43.9	314	14.8	.000*
Centerline Deviation	102	105	98.7	1,310	285,000	.491	.612
Glidepath Deviation	33.9	36.5	37.4	472	42,900	1.17	.311
Elevator Power	.351	.452	.543	1.34	11.0	12.9	.000*
Aileron Power	.383	.477	.533	.822	29.6	2.96	.054
Rudder Power	.070	.109	.147	.213	4.95	4.59	.011*
Elevator Power	3.82	4.03	4.75	34.2	1,350	2.71	.069
Aileron Power	1.76	1.58	1.68	1.24	406	.325	.723
Rudder Power	8.03	7.43	9.12	106	18,000	.627	.535
Wilks Lambda	df_1			df_2	$p(F>F_0)$		
.708	24			404	.000*		
Overhead Pattern							
Pitchout Altitude Deviation	41.5	45.0	38.8	1,380	171,000	.861	.424
Pitchout Bank Deviation	10.6	11.1	10.3	23.5	6,750	.371	.690
Elevator Power	1.77	2.00	1.88	1.90	363	.556	.575
Aileron Power	.527	.543	.547	.016	42.8	.039	.962
Rudder Power	.041	.095	.081	.116	9.69	1.27	.282
Downwind Altitude Deviation	37.4	38.8	44.3	1,920	122,000	1.67	.190
Downwind Score	71.5	66.3	66.2	3,080	134,000	2.45	.088
Elevator Power	1.96	2.07	2.22	2.56	303	.899	.408
Aileron Power	1.16	1.28	1.21	.545	221	.262	.770
Rudder Power	.041	.115	.144	.402	6.66	6.42	.002*
Final Turn Bank Deviation	11.0	10.5	10.1	26.1	5,210	.534	.587
Final Turn Airspeed Dev	5.56	5.99	5.96	8.49	3,130	.289	.750
Elevator Power	1.52	1.67	1.70	1.39	276	.535	.586
Aileron Power	.738	.838	.846	.521	53.0	1.05	.352
Rudder Power	.367	.449	.449	.329	119	.294	.745
Glidepath Deviation	1.05	1.28	1.12	1.88	291	.087	.504
Centerline Deviation	141	138	116	27,000	13,600,000	.211	810
Final Airspeed Deviation	4.54	4.18	5.67	87.4	3,320	2.80	.063
Final Score	11.1	9.46	10.2	103	78,800	.139	.870
Elevator Power	2.89	3.00	3.17	2.85	558	.544	.581
Aileron Power	1.93	1.88	2.05	1.15	355	.346	.708
Rudder Power	3.36	3.83	4.78	75.4	3,110	2.58	.077
Landing Score	76.4	75.3	77.6	193	23,600	.869	.421
Wilks Lambda			df_1	df_2		$p(F>F_0)$	
.755			46	382		.133	

Note. — All univariate F ratios evaluated at $F_{2,213}$.
*p < .05

Table 4. **Ceiling/Visibility Main Effects Across Takeoff, GCA, and Overhead Maneuvers**

Source	$\bar{x}$ (clear)	$\bar{x}$ (minimums)	SSBET	SSW/IN	F	p
		Takeoff				
Heading Deviation	3.01	3.77	30.9	642	10.3	.002*
Pitch Deviation	1.79	1.87	.350	116	.646	.423
Course Deviation	1.07	1.15	.388	221	.376	.541
Airspeed Deviation	3.68	6.46	419	3160	28.4	.000*
Elevator Power	2.45	2.65	2.18	113	4.14	.043*
Aileron Power	.720	.847	.873	57.7	3.24	.073
Rudder Power	.430	.411	.018	25.7	.153	.696
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
.840	7	208		.000*		
		GCA				
Total Score	26.9	22.6	1020	25200	8.66	.004*
Touchdown Score	84.9	82.2	390	30700	2.72	.101
Altitude Deviation	40.4	38.8	146	91800	.340	.561
Airspeed Deviation	2.59	2.59	.003	358	.002	.962
Centerline Deviation	95.0	108	9520	277000	7.36	.008*
Glidepath Deviation	34.7	37.2	358	43000	1.78	.184
Elevator Power	.429	469	.087	12.2	1.53	.218
Aileron Power	.464	.464	.003	30.4	.000	.988
Rudder Power	.108	.109	.000	5.16	.000	.986
Elevator Power	4.28	4.11	1.51	1380	.234	.629
Aileron Power	1.54	1.81	3.74	404	1.98	.161
Rudder Power	8.22	8.17	.129	18100	.002	.969
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
.896	12	203		.029*		
		Overhead Pattern				
Pitchout Altitude Deviation	36.3	47.3	6,540	166,000	8.43	.004*
Pitchout Bank Deviation	11.4	9.95	117	6,650	3.75	.054
Elevator Power	1.81	1.97	1.40	364	.823	.365
Aileron Power	.475	.603	.886	41.9	4.52	.035*
Rudder Power	.083	.062	.024	9.78	.524	.469
Downwind Altitude Deviation	35.8	44.6	4,150	119,000	7.43	.007*
Downwind Score	70.4	62.9	3,020	134,000	4.82	.029*
Elevator Power	1.71	2.46	30.2	275	23.47	.000*
Aileron Power	1.07	1.36	4.46	217	4.40	.037*
Rudder Power	.106	.094	.008	7.06	.239	.626
Final Turn Bank Deviation	9.83	11.20	108	5,130	4.49	.035*
Airspeed Deviation	5.07	6.60	126	3,020	8.93	.003*
Elevator Power	1.47	1.79	5.61	272	4.41	.036*
Aileron Power	.745	.870	.852	52.7	3.46	.064
Rudder Power	.515	.328	1.90	117	3.45	.064
Glidepath Deviation	1.09	1.22	927	292	.678	.411
Centerline Deviation	110	154	107,000	13,600,000	1.68	.196
Final Airspeed Deviation	4.23	5.37	70.8	3,340	4.54	.034*
Final Score	12.7	7.87	1,250	77,700	3.45	.064
Elevator Power	2.86	3.18	5.50	555	2.12	.146
Aileron Power	1.77	2.14	7.58	3.49	4.65	.032*
Rudder Power	3.63	4.35	28.4	3,150	1.93	.168
Landing Score	77.1	75.8	87.2	23,700	.786	.376
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
.754	23	192		.000*		

Note. — All univariate F's evaluated at $F_{1,214}$

Table 5. **Motion Main Effects Across Takeoff, GCA, and Overhead Pattern Maneuvers**

Source	$\bar{x}$(0 DOF)	$\bar{x}$(3 DOF)	$\bar{x}$(6 DOF)	SSBET	SSW/IN	F	p
Takeoff							
Heading Deviation	3.33	3.42	3.41	.377	672	.060	.942
Pitch Deviation	1.70	1.96	1.83	2.39	114	2.24	.109
Course Deviation	1.30	1.03	1.00	3.83	218	1.87	.156
Airspeed Deviation	4.12	5.81	5.28	107	3,470	3.29	.039
Elevator Power	2.52	2.48	2.67	1.47	113	1.38	.254
Aileron Power	.582	.801	.967	5.38	53.2	10.77	.000*
Rudder Power	.487	.346	.428	.719	25.0	3.07	.048*
Wilks Lambda	df_1		df_2		$p(F>F_0)$		
.823	14		414		.000*		
GCA							
Total Score	27.3	24.3	22.7	771	25,500	3.23	.042*
Touchdown Score	84.4	83.4	82.9	86.8	31,100	.298	.743
Altitude Deviation	33.2	41.2	44.3	4,720	87,300	5.76	.004*
Airspeed Deviation	2.40	2.44	2.92	12.0	346	3.70	.026*
Centerline Deviation	96.7	102	106	3,060	283,000	1.15	.319
Glidepath Deviation	36.3	35.6	36.0	19.6	43,400	.048	.953
Aileron Power	.379	.395	.572	1.66	10.7	16.6	.000*
Rudder Power	.276	.457	.660	5.31	25.1	22.5	.000*
Elevator Power	.091	.113	.123	.039	5.12	.806	.448
Aileron Power	4.29	3.70	4.61	30.9	1,350	2.44	.089
Rudder Power	1.53	1.43	2.06	16.9	390	4.61	.001*
Elevator Power	8.56	6.83	9.20	216	17,900	1.29	.278
Wilks Lambda	df_1		df_2		$p(F>F_0)$		
.695	24		404		.000*		
Overhead Pattern							
Pitchout Altitude Deviation	36.9	40.6	47.8	4390	168000	2.78	.064
Pitchout Bank Deviation	10.1	11.2	10.8	39.5	6730	.625	.536
Elevator Power	2.16	1.72	1.79	8.16	357	2.43	.090
Aileron Power	.439	.513	.666	1.93	40.9	5.02	.007*
Rudder Power	.062	.069	.087	.024	9.78	.258	.773
Downwind Altitude Deviation	34.0	41.4	45.3	4750	119000	4.26	.015*
Downwind Score	70.2	65.5	64.2	1430	135000	1.12	.327
Elevator Power	2.22	1.74	23.0	13.0	292	4.74	.009*
Aileron Power	.895	1.17	15.8	17.0	205	8.85	.000*
Rudder Power	.098	.110	.092	.013	7.05	.191	.826
Final Turn Bank Deviation	9.95	10.6	11.0	43.9	5200	.899	.409
Final Turn Airspeed Deviation	5.68	6.14	5.69	9.74	3130	.331	.719
Elevator Power	1.55	1.47	1.88	6.59	271	2.59	.077
Aileron Power	.605	.830	.987	5.31	58.2	11.73	.000*
Rudder Power	.483	.418	.365	.504	119	.452	.637
Glidepath Deviation	1.14	1.12	1.20	.233	293	.085	.919
Centerline Deviation	128	134	134	1,810	13,700,000	.014	.986
Final Airspeed Deviation	4.88	4.73	4.79	.867	3140	.027	.973
Final Score	8.20	12.2	10.5	574	78300	.781	.459
Elevator Power	3.28	2.74	3.04	10.6	550	2.053	.131
Aileron Power	1.70	2.05	2.12	7.28	349	2.20	.111
Rudder Power	4.40	3.48	4.09	31.0	3150	1.05	.352
Landing Score	78.1	76.2	75.2	314	23500	1.42	.244
Wilks Lambda	df_1		df_2		$p(F>F_0)$		
.657	46		382		.000*		

*$p < .05$.

All univariate F's evaluated at $F_{2,213}$.

Table 6. **Field of View Main Effects Across Takeoffs, GCAs, and Overhead Pattern Maneuvers**

Source	$\bar{X}$ (masked)	$\bar{X}$ (full)	SSBET	SSW/IN	F	p
		Takeoff				
Heading Deviation	3 50	3.28	2.72	670	.869	.353
Pitch Attitude 1.8ı	1.86	1.80	.150	116	.277	.599
Course Deviation	1.23	.993	2.96	219	2.90	.089
Airspeed Deviation	5.52	4.62	43.5	3,530	2.63	.106
Elevator Power	2.61	2.50	.615	114	1.152	284
Rudder Power	.868	.698	.156	57.0	5.85	.016*
Airleron Power	.428	.413	.013	25.7	107	.744
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
.949	7	203		.141		
		GCA				
Total Score	25.1	24.5	18.7	26,200	.153	.696
Touchdown Score	83.0	84.2	88.5	31,000	.610	.436
Altitude Deviation	42.0	37.2	1,260	90,700	2.96	.086
Airspeed Deviation	27.1	24.6	3.35	355	2.02	.157
Centerline Deviation	99.4	104	1,150	285,000	.867	.353
Glidepath Deviation	34.8	37.1	298	43,100	1.48	.225
Elevator Power	.472	.425	.122	12.2	2.14	.145
Aileron Power	.530	.398	.938	29.4	6.82	.009*
Rudder Power	.102	.115	.008	5.15	.333	.564
Elevator Power	4.18	4.21	.061	1,380	.009	.922
Aileron Power	1.76	1.58	1.77	406	.934	.335
Rudder Power	8.72	7.67	60.4	18,000	.718	.398
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
.922	12	203		.155		
		Overhead Pattern				
Pitchout Altitude	44.1	39.4	1,200	171,000	1.50	.221
Pitchout Bank	11.0	10.4	23.0	6,750	.731	.394
Elevator Power	1.87	1.91	.081	365	.047	.828
Aileron Power	.595	.483	.681	42.1	3.46	.069
Rudder Power	.087	.058	.045	9.76	.977	.329
Downwind Attitude Deviation	41.1	39.3	164	123,000	.284	.595
Downwind Score	62.9	70.5	3,130	134,000	5.01	.026*
Elevator Power	2.13	2.04	.519	305	.364	.547
Aileron Power	1.34	1.09	3.16	218	3.09	.080
Rudder Power	.092	.108	.013	7.05	.397	.530
Final Turn Bank Deviation	11.5	9.62	181	5,060	7.67	.006*
Final Turn Airspeed Deviation	5.75	5.92	1.57	3,140	.107	.744
Elevator Power	1.65	1.62	.054	278	.042	.839
Aileron Power	.891	.724	1.51	52.0	6.19	.014*
Rudder Power	.404	.439	.064	119	.114	.735
Glidepath Deviation	1.26	1.04	2.67	291	1.97	.162
Centerline Deviation	165	99.1	233,000	1,340,000	3.71	.055
Final Airspeed Deviation	5.51	4.09	108	3,300	7.01	.009*
Final Score	9.24	11.3	233	78,700	.635	.426
Elevator Power	3.02	3.03	.006	560	.002	.962
Aileron Power	2.07	1.84	2.76	354	1.67	.198
Rudder Power	4 02	3.96	151	3,180	.010	.919
Landing Score	76.4	76 6	2.61	23,800	.023	.878
Wilks Lambda	df_1	df_2		$P(F>F_0)$		
843	23	192		.0572		

Note. — All Univariate F's evaluated at $F_{1,214}$

* $p < .05$.

few cases of significance in the univariate analysis. Eighteen of the 23 variables measured in the overhead pattern showed better, although not necessarily significantly better, performance under the full FOV.

G-Seat. The final system main effect evaluated was the G-seat. The data analyses on the G-seat variable are listed in Table 7.

The G-seat variable reached significance in the omnibus multivariate test for the takeoff and GCA maneuvers, but not for the overhead pattern.

Inspection of the univariate analysis data in Table 7 reveals three significant F ratios ($p<.05$) for the takeoff maneuver. Overall, three of the seven dependent measures show improved performance with the G-seat present.

The GCA maneuver produced two significant univariate F ratios, both of which indicated better performance with the G-seat on. Of the 12 variables in the matrix, although only these two were significant, seven of the 12 suggested improved performance under the G-seat on condition.

In the overhead pattern maneuver, 13 of 23 variables favored the G-seat condition; however, the effect was so small that overall performance was relatively unchanged as a function of G-seat conditions.

The maneuvers used in the second design were slow flight and aileron roll. The independent variables manipulated in the performance of these tasks were turbulence, platform motion, FOV, and G-seat.

3^4 Environmental Variable. Table 8 lists the means, sums of squares, univariate F-statistics, and associated probability levels for the single environmental variable (turbulence) investigated in the slow flight and aileron roll maneuvers. As can be discerned from inspection of these tables, the omnibus tests were nonsignificant; however, examination of the individual variable means disclosed that four of the seven dependent measures in slow flight suggested that superior performance was evidenced under no turbulence conditions. Contrary to this finding, seven of the eight dependent measures used in the aileron roll suggested that performance improved when some level of turbulence was present.

3^4 System Variables. Table 9 lists the effects observed when the system configuration variables were analyzed.

Of the three system main effects evaluated by multivariate techniques in the slow flight maneuver, the most prominent was the motion effect ($p<.001$). Those variables which attained significance in the univariate analysis also indicated that subject performance was superior in the absence of platform motion.

The FOV and the G-seat variables produced mixed results in the slow flight maneuver as evidenced by the nonsignificant multivariate and univariate tests (Table 9). Surprisingly, the majority of the dependent measures in the slow flight maneuver suggested that superior performance was evidenced in the masked FOV condition.

The FOV main effect was significant in the multivariate analysis of pilot performance of the aileron roll. The step-down univariate analysis confirmed this effect with a majority of the system output and pilot input dependent measures reflecting improved performance under the full FOV condition.

The G-seat main effect did not attain statistical significance in this maneuver for either the multivariate analysis or for any of the individual measures at the univariate level.

Environmental by Environmental Variable Interactions in the 3^3 2^3 Design

None of the environmental by environmental variable interactions reached significance in the omnibus tests for any of the three maneuvers. This obvious lack of synergistic effects between environmental factors was somewhat surprising and will be pursued in the Discussion Section.

System by System Variable Interactions in the 3^3 2^3 Design

The system variables, consisting of platform motion, FOV, and G-seat, produced the interactions shown in Table 10.

Considering all three maneuvers used in this design, only two of the three possible first order interactions of the system variables attained statistical significance. The FOV by G-seat interaction did not reach significance in any of the three maneuvers

Motion by FOV. The motion by FOV interaction was statistically significant in the multivariate analysis for both the takeoff and GCA maneuvers. Table 11 and 12 give the dependent

Table 7. **G-Seat Main Effects Across Takeoffs, GCAs, and Overhead Pattern Maneuvers**

Source	$\bar{x}$ (Off)	$\bar{x}$ (On)	SSBET	SSW/IN	F	p
Takeoff						
Heading Deviation	3.34	3.44	.594	672	.189	.664
Pitch Attitude	1.96	1.70	3.63	113	6.91	.009*
Course Deviation	1.02	1.20	1.66	220	1.62	.205
Airspeed Deviation	5.63	4.51	68.0	3,510	4.15	.043*
Elevator Power	2.47	2.63	1.36	113	2,559	.111
Rudder Power	.825	.741	.376	58.2	1.38	.241
Aileron Power	.367	.474	.619	25.1	5.28	.022*
Wilks Lambda		df_1		df_2		$p(F>F_0)$
.909		7		208		.005*
GCA						
Total Score	23.5	26.0	355	25,900	2.93	.088
Touchdown Score	84.0	83.2	37.5	31,100	.258	.612
Altitude Deviation	44.0	35.2	4,240	87,800	10.2	.002*
Airspeed Deviation	2.70	2.48	2.76	356	1.66	.199
Centerline Deviation	108	95.3	8,760	277,000	6.76	.010*
Glidepath Deviation	37.3	34.6	414	43,000	2.06	.152
Elevator Power	.425	.472	.118	12.2	2.07	.151
Aileron Power	.483	.445	.075	30.3	.529	.468
Rudder Power	.113	.104	.005	5.16	.186	.666
Elevator Power	3.97	4.42	11.1	1,370	1.73	.189
Aileron Power	1.66	1.69	.035	407	.018	.893
Rudder Power	7.77	8.62	39.4	18,000	.468	.495
Wilks Lambda		df_1		df_2		$p(F>F_0)$
.855		12		203		.001*
Overhead Pattern						
Pitchout Altitude	42.3	41.3	52.9	172,000	.066	.798
Pitchout Bank	11.7	9.67	221	6,550	7.23	.008*
Elevator Power	1.68	2.09	9.19	356	5.53	.020*
Aileron Power	.525	.553	.042	42.8	.208	.649
Rudder Power	.062	.083	.025	9.78	.553	.458
Downwind Altitude Deviation	40.8	39.6	72.6	124,000	.126	.723
Downwind Score	67.2	66.1	63.7	137,000	.100	.753
Elevator Power	1.94	2.23	4.27	301	3.04	.083
Aileron Power	1.16	1.27	.721	221	.698	.404
Rudder Power	.116	.084	.053	7.01	1.599	.207
Final Turn Bank Deviation	10.6	10.5	1.34	5,240	.055	.815
Final Turn Airspeed Deviation	5.89	5.78	.738	3,140	.050	.822
Elevator Power	1.52	1.74	2.73	275	2.126	.146
Aileron Power	.816	.799	.017	53.5	.067	.796
Rudder Power	.411	.432	.023	119	.041	.840
Glidepath Deviation	1.27	1.03	3.14	290	2.32	.130
Centerline Deviation	159	105	153,000	1,350,000	2.43	.121
Final Airspeed Deviation	4.89	4.71	1.77	3,410	.111	.739
Final Score	12.5	8.05	1,080	77,800	2.96	.087
Elevator Power	2.78	3.27	1,229	548	5.05	.026*
Aileron Power	2.03	1.87	1.36	355	.821	.366
Rudder Power	4.00	3.98	.040	3,180	.003	.958
Landing Score	76.0	77.0	54.0	23,800	.487	.486
Wilks Lambda		df_1		df_2		$p(F>F_0)$
.864		23		192		.159

Note. – All univariate F's evaluted at $F_{1,214}$.
*p <.05.

Table 8. **Turbulence Main Effects for the Slow Flight and Aileron Roll Maneuvers**

Source	$\bar{x}$ (None)	$\bar{x}$ (Light)	$\bar{x}$ (Mod)	SSBET	SSW/IN	F	p
		Slow Flight					
Altitude Deviation	37.3	44.2	50.1	2,210	43,000	2.01	.141
Airspeed Deviation	1.67	1.81	2.28	5.46	36.8	5.79	.005*
Slip Indicator Deviation	.232	.223	.229	.001	.356	.122	.885
Total Score	36.9	32.7	23.6	2,990	18,300	5.29	.007*
Elevator Power	.631	.638	.898	.125	16.3	2.99	.056
Aileron Power	.379	.411	.509	.228	6.95	1.277	.285
Rudder Power	.058	.066	.054	.002	.366	.210	.811
Wilks Lambda		df_1		df_2			$p(F>F_0)$
.796		14		144			.249
		Aileron Roll					
Bank in Deviation	2.12	1.76	2.29	3.98	146	1.06	.351
Roll Accel	13.5	11.4	13.1	70.3	3,620	.756	.473
Roll Score	39.7	35.0	40.8	514	38,900	.516	.599
Bank Out Deviation	3.61	3.63	3.22	2.87	214	.524	.594
Aileron Power (In)	1.89	1.45	1.72	2.71	266	.399	.673
Aileron Power (Roll)	1.55	1.14	1.25	2.39	128	.729	.485
Aileron Power (Out)	1.47	.949	1.16	3.69	142	1.01	.369
Total Score	29.0	28.6	27.7	22.4	33,000	.027	.974
Wilks Lambda		df_1		df_2			$p(F>F_0)$
.840		16		142			.672

Note. — All univariate F's evaluated at $F_{2,78}$.
*P < .05.
Mod = Moderate

Table 9 (*Continued*)

Source	$\bar{x}$ (Off)	$\bar{x}$ (SP Only)	$\bar{x}$ (On)	SSBET	SSW/IN	F	p
			G-Seat				
Bank In Deviation	2.17	2.12	1.87	1.39	149	.363	.696
Roll Acceleration	13.1	12.9	12.5	7.53	3,690	.080	.924
Roll Score	42.8	36.3	36.4	761	38,600	.769	.467
Bank Out Deviation	3.75	3.39	3.32	2.85	214	.520	.596
Aileron Power (In)	2.03	1.43	1.60	5.10	263	.756	.473
Aileron Power (Roll)	1.49	1.22	1.23	1.28	129	.387	.681
Aileron Power (Out)	1.45	1.16	.968	3.20	143	.875	.421
Total Score	29.1	29.0	27.2	61.8	32,900	.073	.929
Wilks Lambda		df_1		df_2			$p(F>F_0)$
.824		16		142			.570

Note. — All univariate F's evaluated at $F_{2,78}$.
*p < .05.
SP only = Seat Pan Only.

Table 10. Significant System by System Variable Interactions Across All Maneuvers

Source	Wilks Lambda (λ)	df_1	df_2	F_0	$p(F>F_0)$
		Takeoff			
Motion by G-Seat	.667	14	220	3.52	.000
Motion by Field of View	.787	14	220	1.98	.019
		GCA			
Motion by Field of View	.585	24	210	2.69	.000
		Overhead Pattern			
Motion by G-Seat	.494	46	188	1.72	.006

Table 11. Field of View by Motion Interaction Cell Means for Takeoff

	Field of View (full)			Field of View (masked)		
Source	0 DOF	3 DOF	6 DOF	0 DOF	3 DOF	6 DOF
1. Heading Deviation	3.24	3.55	3.69	3.41	3.28	3.13
2. To/Att Deviation	1.04	1.97	1.75	1.56	1.93	1.91
3. Course Deviation	1.63	1.05	1.00	.96	1.01	1.00
4. Airspeed Deviation	4.61	5.72	6.22	3.63	5.90	4.32
5. Elevator Power	2.46	2.49	2.86	2.57	2.45	2.47
6. Aileron Power	.57	.88	1.15	.59	.72	.78
7. Rudder Power	.46	.35	.47	.51	.34	.38

Note. — DOF = degrees of freedom, motion platform.

Table 9 (*Continued*)

Source	$\bar{x}$ (Off)	$\bar{x}$ (SP Only)	$\bar{x}$ (On)	SSBET	SSW/IN	F	p
			G-Seat				
Bank In Deviation	2.17	2.12	1.87	1.39	149	.363	.696
Roll Acceleration	13.1	12.9	12.5	7.53	3,690	.080	.924
Roll Score	42.8	36.3	36.4	761	38,600	.769	.467
Bank Out Deviation	3.75	3.39	3.32	2.85	214	.520	.596
Aileron Power (In)	2.03	1.43	1.60	5.10	263	.756	.473
Aileron Power (Roll)	1.49	1.22	1.23	1.28	129	.387	.681
Aileron Power (Out)	1.45	1.16	.968	3.20	143	.875	.421
Total Score	29.1	29.0	27.2	61.8	32,900	.073	.929
Wilks Lambda		df_1		df_2			$p(F>F_0)$
.824		16		142			.570

Note. — All univariate F's evaluated at $F_{2,78}$.
*p < .05.
SP only = Seat Pan Only.

Table 10. Significant System by System Variable Interactions Across All Maneuvers

Source	Wilks Lambda (λ)	df_1	df_2	F_0	$p(F>F_0)$
		Takeoff			
Motion by G-Seat	.667	14	220	3.52	.000
Motion by Field of View	.787	14	220	1.98	.019
		GCA			
Motion by Field of View	.585	24	210	2.69	.000
		Overhead Pattern			
Motion by G-Seat	.494	46	188	1.72	.006

Table 11. Field of View by Motion Interaction Cell Means for Takeoff

Source	Field of View (full)			Field of View (masked)		
	0 DOF	3 DOF	6 DOF	0 DOF	3 DOF	6 DOF
1. Heading Deviation	3.24	3.55	3.69	3.41	3.28	3.13
2. To/Att Deviation	1.04	1.97	1.75	1.56	1.93	1.91
3. Course Deviation	1.63	1.05	1.00	.96	1.01	1.00
4. Airspeed Deviation	4.61	5.72	6.22	3.63	5.90	4.32
5. Elevator Power	2.46	2.49	2.86	2.57	2.45	2.47
6. Aileron Power	.57	.88	1.15	.59	.72	.78
7. Rudder Power	.46	.35	.47	.51	.34	.38

Note. — DOF = degrees of freedom, motion platform.

Table 12. **Motion by Field of View Interaction Cell Means for GCA**

Source	Full Field of View			Masked Field of View		
	0 DOF Motion	3 DOF	6 DOF	0 DOF Motion	3 DOF	6 DOF
1. Total Score	28.15	23.92	23.07	26.39	24.62	22.37
2. Touchdown	83.74	84.15	80.94	85.12	82.70	84.86
3. Altitude Deviation	53.20	44.14	46.65	31.22	38.33	41.94
4. Airspeed Deviation	2.47	2.63	3.02	2.33	2.24	2.81
5. Centerline Deviation	95.47	100.46	102.12	97.93	104.52	109.48
6. Glidepath Deviation	34.91	36.48	32.94	37.67	34.63	39.08
7. Elevator Power	.38	.41	.61	.36	.37	.53
8. Aileron Power	.25	.49	.83	.29	.41	.48
9. Rudder Power	.07	.07	.15	.10	.14	.08
10. Elevator Power	3.92	3.40	5.21	4.64	3.98	4.00
11. Aileron Power	1.36	1.56	2.36	1.69	1.29	1.76
12. Rudder Power	7.47	7.54	11.13	9.62	6.11	7.25

variables means for the treatment cells of both maneuvers. Table 13 gives ratings of the mean performance for these maneuvers. Inspection of this table reveals best performance falling in the no motion, full FOV condition in the GCA. In this maneuver, performance generally deteriorates with the introduction of platform motion. The same deterioration in performance occurred in the takeoff maneuver under the three and six DOF platform motion conditions. The analysis of the data from both maneuvers suggests that superior performance occurred under the masked FOV condition. The best performance in the takeoff maneuver occurred with the masked FOV, but when 6 DOF of platform motion was present.

Table 13. **Motion by FOV Interaction Mean Ratings for the GCA and Takeoff Maneuvers**

GCA

Motion	Field of View: Full	Masked
0 DOF	2.29*	2.83
3 DOF	3.37	2.83
6 DOF	5.33*	4.33

χ^2 crit = 2.99

Takeoff

Motion	Full	Masked
0 DOF	3.00	2.85
3 DOF	4.42	3.14
6 DOF	4.78	2.78

χ^2 crit = 3.32

*Indicates significant difference.

Table 16. **Motion by G-Seat Interaction Mean Ratings for the Takeoff and Overhead Pattern Maneuvers**

Takeoff

		G-Seat Off	G-Seat On
Motion	0 DOF	2.64	3.28
	3 DOF	3.21	3.71
	6 DOF	4.57	3.57

χ^2 crit = 3.32

Overhead Pattern

		G-Seat Off	G-Seat On
Motion	0 DOF	2.48*	3.22
	3 DOF	3.76	3.20
	6 DOF	4.37*	3.98

χ^2 crit = 1.82

*Denotes significant difference.

System by Environmental Variable Interactions in the 3^3 2^3 Design

The third type of interaction considered in this study was the system by environmental variable interaction. These data are listed in Table 17.

Of the nine possible first order interactions between environmental and system variables, only three attained statistical significance in the multivariate test.

Turbulence by Motion. The turbulence by motion interaction was significant in all three maneuvers. Table 18, 19, and 20 present the treatment cell means across all dependent variables.

Table 21 shows the mean ratings of performance for this interaction across the three maneuvers. In all cases, best performance was demonstrated in the no motion, no turbulence conditions. Thereafter, pilot performance consistently became poorer as turbulence and platform motion increased.

C/V by FOV. The second interaction, ceiling visibility by FOV, and the final significant interaction of this type, C/V by G-seat, were manifested only within the analysis of the GCA maneuver. Table 22 gives the mean performances for the C/V by FOV treatment cells.

C/V by G-Seat. As stated above, this interaction was statistically significant only for the GCA maneuver. Table 23 lists the mean performance observed for the C/V by G-seat treatment cells.

Analysis of C/V Interactions. Table 24 shows the differences in the mean ratings for the two C/V interactions. In both instances, superior performance was evidenced in the clear C/V conditions. This performance was accompanied in the first interaction with the masked FOV, and in the second with the G-seat being operational.

The Second Order Interaction in the 3^3 2^3 Design. The most surprising interaction produced was a second order interaction, C/V by FOV by G-seat, that reached probability levels of $p = < .025$, $p = < .01$, and $p = < .001$ in the multivariate analysis of the takeoff, GCA, and overhead pattern maneuvers, respectively. Tables 25, 26 and 27 contain the mean performance data on these maneuvers. Table 28 contains the mean ratings of performance for this interaction across all three

Table 16. **Motion by G-Seat Interaction Mean Ratings for the Takeoff and Overhead Pattern Maneuvers**

Takeoff

		G-Seat Off	G-Seat On
Motion	0 DOF	2.64	3.28
	3 DOF	3.21	3.71
	6 DOF	4.57	3.57

χ^2 crit = 3.32

Overhead Pattern

		G-Seat Off	G-Seat On
Motion	0 DOF	2.48*	3.22
	3 DOF	3.76	3.20
	6 DOF	4.37*	3.98

χ^2 crit = 1.82

*Denotes significant difference.

System by Environmental Variable Interactions in the 3^3 2^3 Design

The third type of interaction considered in this study was the system by environmental variable interaction. These data are listed in Table 17.

Of the nine possible first order interactions between environmental and system variables, only three attained statistical significance in the multivariate test.

Turbulence by Motion. The turbulence by motion interaction was significant in all three maneuvers. Table 18, 19, and 20 present the treatment cell means across all dependent variables.

Table 21 shows the mean ratings of performance for this interaction across the three maneuvers. In all cases, best performance was demonstrated in the no motion, no turbulence conditions. Thereafter, pilot performance consistently became poorer as turbulence and platform motion increased.

C/V by FOV. The second interaction, ceiling visibility by FOV, and the final significant interaction of this type, C/V by G-seat, were manifested only within the analysis of the GCA maneuver. Table 22 gives the mean performances for the C/V by FOV treatment cells.

C/V by G-Seat. As stated above, this interaction was statistically significant only for the GCA maneuver. Table 23 lists the mean performance observed for the C/V by G-seat treatment cells.

Analysis of C/V Interactions. Table 24 shows the differences in the mean ratings for the two C/V interactions. In both instances, superior performance was evidenced in the clear C/V conditions. This performance was accompanied in the first interaction with the masked FOV, and in the second with the G-seat being operational.

The Second Order Interaction in the 3^3 2^3 Design. The most surprising interaction produced was a second order interaction, C/V by FOV by G-seat, that reached probability levels of p = <.025, p = <.01, and p = <.001 in the multivariate analysis of the takeoff, GCA, and overhead pattern maneuvers, respectively. Tables 25, 26 and 27 contain the mean performance data on these maneuvers. Table 28 contains the mean ratings of performance for this interaction across all three

Table 17. **Significant System by Environmental Interactions Across all Maneuvers**

Source	Wilks Lambda (λ)	df_1	df_2	F_0	$p(F>F_0)$
Takeoff					
Turbulence by Motion	.639	28	398.03	1.877	.005
C/V by FOV by G	.867	7	110	2.414	.024
GCA					
Turbulence by Motion	.480	48	406.50	1.77	.001
C/V by FOV	.774	12	105	2.54	.005
C/V by G	.774	12	105	2.54	.005
C/V by FOV by G	.688	12	105	3.95	.000
Overhead Pattern					
Turbulence by Motion	.312	92	374.56	1.39	.017
C/V by FOV by G	.586	23	94	2.88	.000
Slow Flight					
None					
Aileron Roll					
None					

C/V = Ceiling/Visibility
FOV = Field of View
G = G-Seat

Table 18. **Turbulence by Motion Interaction Cell Means for Takeoff**

Source	0 DOF Motion			3 DOF Motion			6 DOF Motion		
	No Turb	Light Turb	Mod Turb	No Turb	Light Turb	Mod Turb	No Turb	Light Turb	Mod Turb
Heading	3.32	3.43	3.22	3.60	3.43	3.22	3.01	3.50	3.72
Altitude Deviation	1.86	1.55	1.68	1.79	2.20	1.87	2.09	1.82	1.57
Course Deviation	1.13	1.55	1.20	.90	1.12	1.05	.98	1.05	.97
Airspeed	5.27	3.26	3.82	4.60	6.16	6.69	4.54	5.75	5.52
Elevator Power	2.29	2.74	2.51	2.44	2.42	2.56	2.42	2.63	2.94
Aileron Power	.53	.59	.60	.78	.83	.77	.76	1.01	1.12
Rudder Power	.38	.48	.58	.26	.38	.39	.47	.33	.48

Note. — Turb = Turbulence.

Table 19. **Turbulence by Motion Interaction Cell Means for GCA**

Source	0 DOF Motion			3 DOF Motion			6 DOF Motion		
	No Turb	Light Turb	Mod Turb	No Turb	Light Turb	Mod Turb	No Turb	Light Turb	Mod Turb
Total Score	26.601	27.23	27.98	25.69	22.96	24.16	27.06	18.05	23.06
Touchdown Score	83.56	82.96	86.76	80.31	83.05	86.42	83.50	81.65	83.56
Altitude Deviation	30.94	32.70	35.99	37.43	37.51	48.76	35.35	50.67	46.87
Airspeed Deviation	1.74	2.42	3.04	2.19	2.48	2.64	2.13	2.95	3.68
Centerline Deviation	102.53	92.23	95.35	101.92	106.26	99.29	100.21	115.73	101.46
Glidepath Deviation	34.30	35.94	38.62	35.32	35.79	35.56	32.15	37.85	38.03
Elevator Power	.30	.40	.42	.35	.33	.49	.39	.61	.70
Aileron Power	.23	.28	.31	.44	.42	.49	.47	.71	.79
Rudder Power	.07	.07	.12	.05	.09	.18	.08	.15	.13
Elevator Power	4.03	4.13	4.69	3.55	3.26	4.23	3.84	4.67	5.30
Aileron Power	7.44	8.31	9.92	8.74	5.60	6.14	7.89	8.38	11.31

Note. — Turb = Turbulence.

Table 20. **Turbulence by Motion Interaction Cell Means for Overhead Pattern**

Source	No Turbulence			Light Turbulence			Moderate Turbulence		
	0 DOF Motion	3 DOF	6 DOF	0 DOF Motion	3 DOF	6 DOF	0 DOF Motion	3 DOF	6 DOF
1. Altitude Deviation	38.65	38.59	47.36	37.79	44.08	53.03	34.32	39.06	42.92
2. Bank Deviation	8.91	11.46	11.35	10.94	12.64	9.79	10.51	9.36	11.15
3. Elevator Power	1.29	1.64	1.48	2.22	1.64	2.13	2.06	1.85	1.73
4. Aileron Power	.45	.63	.49	.48	.39	.75	.37	.51	.74
5. Rudder Power	.05	.02	.04	.08	.03	.16	.04	.14	.05
6. Altitude Deviation	35.79	38.85	37.64	32.91	38.14	46.47	33.18	47.13	52.70
7. Downwind Score	70.17	71.74	72.44	69.28	66.32	63.32	71.21	58.48	59.65
8. Elevator Power	2.15	1.76	1.95	2.38	1.46	2.37	2.11	1.99	2.56
9. Aileron Power	.80	1.29	1.38	.94	1.13	1.76	.94	1.09	1.58
10. Rudder Power	.05	.04	.02	.08	.12	.13	.15	.16	.11
11. Bank Deviation	10.11	11.58	11.12	10.27	11.05	10.18	9.45	9.18	11.73
12. Airspeed Deviation	4.36	6.30	6.00	5.19	7.54	5.24	7.47	4.56	5.83
13. Elevator Power	1.32	1.52	1.71	1.78	1.47	1.75	1.53	1.41	2.16
14. Aileron Power	.56	.83	.80	.62	.89	.99	.62	.75	1.15
15. Rudder Power	.33	.50	.25	.70	.27	.36	.40	.47	.47
16. Altitude Deviation	1.17	.89	1.09	1.13	1.09	1.60	1.11	1.35	.88
17. Centerline Deviation	183.57	96.39	143.72	73.68	141.35	200.07	125.31	163.29	59.01
18. Airspeed Deviation	5.70	4.15	3.77	3.49	3.53	5.50	5.44	6.48	5.09
19. Final Score	5.86	17.39	10.17	12.90	10.09	5.36	5.82	9.05	15.85
20. Elevator Power	3.25	2.35	3.07	3.05	2.90	3.03	3.53	2.96	3.01
21. Aileron Power	1.59	1.91	2.27	1.58	2.12	1.92	1.91	2.09	2.14
22. Rudder Power	3.64	3.22	3.20	4.72	3.26	3.50	4.81	3.96	5.55
23. Total Score	80.57	73.14	75.90	73.31	75.02	77.53	80.36	80.34	72.10

Table 21. **Turbulence by Motion Interaction Mean Ratings for the Takeoff, GCA and Overhead Pattern Maneuvers**

Takeoff

Turbulence

		None	Light	moderate
	0 DOF	4.07	4.71	4.78
Motion	3 DOF	4.28	6.07	4.78
	6 DOF	4.92	6.00	6.35

χ^2 crit = 5.74

GCA

Turbulence

		None	Light	Moderate
	0 DOF	3.08	3.58	5.08
Motion	3 DOF	4.33	4.41	5.33
	6 DOF	3.83	3.75	7.41

χ^2 crit = 4.37

Overhead Pattern

Turbulence

		None	Light	Moderate
	0 DOF	4.06	4.69	4.52
Motion	3 DOF	4.21	4.60	5.32
	6 DOF	4.52	6.65	6.39

χ^2 crit = 3.17

Table 22. **Ceiling/Visibility by FOV Interaction Cell Means for GCA**

Source	Full Field of View		Masked Field of View	
	Clear	Minimums	Clear	Minimums
Total Score	25.51	24.58	28.34	20.58
Touchdown Score	85.29	80.61	84.58	83.88
Altitude RMS Error	46.57	37.42	34.23	40.10
Airspeed RMS Error	2.82	2.59	2.34	2.58
Centerline Deviation	98.17	100.54	91.88	116.07
Glidepath Deviation	34.80	34.75	34.53	39.73
Elevator Power	.46	.47	.39	.45
Aileron Power	.57	.48	.35	.44
Rudder Power	.10	.10	.11	.11
Elevator Power	4.63	3.72	3.92	4.50
Aileron Power	1.78	1.74	1.30	1.86
Rudder Power	9.70	7.74	6.73	8.59

Table 23. **Ceiling/Visibility by G-Seat Interaction Cell Means for GCA**

Source	G-Seat Off		G-Seat On	
	Clear	Minimums	Clear	Minimums
Total Score	25.25	21.69	28.61	23.46
Touchdown Score	84.57	33.44	85.29	81.05
Altitude RMS Error	49.87	38.11	30.93	39.41
Airspeed RMS Error	2.72	2.68	2.44	2.50
Centerline Deviation	100.14	115.93	89.91	100.68
Glidepath Deviation	34.68	37.99	32.65	36.49
Elevator Power	.40	.44	.45	.48
Aileron Power	.49	.46	.42	.46
Rudder Power	.11	.10	.09	.11
Elevator Power	3.92	4.01	4.63	4.21
Aileron Power	1.52	1.78	1.54	1.82
Rudder Power	7.91	7.61	8.52	8.72

Table 24. **Ceiling/Visibility by FOV and Ceiling/Visibility by G-Seat Interaction Mean Ratings for the GCA Maneuver**

Ceiling/Visibility		Field of View: Full	Field of View: Masked
	Clear	2.95*	1.37*°
	Minimums	2.54	3.29°

χ^2 crit = 1.47

Ceiling/Visibility		G-Seat: Off	G-Seat: On
	Clear	2.37	1.66*
	Minimums	2.70	3.25*

χ^2 crit = 1.47

*°Denotes significant differences.

Table 25. **Ceiling/Visibility by FOV by G-Seat Interaction Cell Means for Takeoff**

	G-Seat Off				G-Seat On			
	Full Field of View		Masked Field of View		Full Field of View		Masked Field of View	
Source	Clear	Minimum	Clear	Minimum	Clear	Minimum	Clear	Minimum
1. Heading Deviation	3.08	3.86	2.83	3.55	3.12	3.92	2.99	3.71
2. To/Att Deviation	1.90	1.96	1.92	2.04	1.70	1.85	1.62	1.61
3. Course Deviation	.86	.99	.98	1.24	1.53	1.51	.88	.86
4. Airspeed Deviation	5.59	6.26	3.15	7.51	2.94	7.27	3.01	4.79
5. Elevator Power	2.24	2.71	2.22	2.71	2.76	2.69	2.57	2.49
6. Aileron Power	.96	.85	.57	.90	.70	.92	.62	.69
7. Rudder Power	.42	.32	.31	.39	.54	.40	.42	.51

Table 26. **Ceiling/Visibility by FOV by G-Seat Interaction Cell Means GCA**

Source	G-Seat Off				G-Seat On			
	Full Field of View		Masked Field of View		Full Field of View		Masked Field of View	
	Clear	Minimum	Clear	Minimum	Clear	Minimum	Clear	Minimum
1. Total Score	22.29	25.15	28.21	18.24	28.74	24.02	28.47	22.91
2. Touchdown Score	84.52	84.33	84.62	82.54	86.05	76.88	84.54	85.21
3. Alt Deviation Error	62.04	32.96	37.64	43.26	31.10	41.88	30.76	36.94
4. Airspeed Deviation Error	3.08	2.58	2.35	2.77	2.56	2.61	2.32	2.39
5. Centerline Deviation	107.89	104.17	92.40	127.68	88.45	96.90	91.37	104.47
6. Glidepath Deviation	37.23	34.64	36.13	41.34	32.38	34.86	32.92	38.11
7. Elevator Power	.44	.46	.35	.43	.48	.49	.42	.48
8. Aileron Power	.63	.44	.36	.49	.51	.52	.33	.39
9. Rudder Power	.12	.08	.11	.12	.08	.11	.11	.10
10. Elevator Power	3.84	3.42	4.01	4.60	5.42	4.03	3.84	4.39
11. Aileron Power	1.96	1.32	1.10	2.24	1.60	2.16	1.49	1.48
12. Rudder Power	9.35	6.62	6.47	8.61	10.04	8.87	7.00	8.57

Table 27. **Ceiling/Visibility by FOV by G-Seat Interaction Cell Means for Overhead Pattern**

Source	G-Seat Off				G-Seat On			
	Full Field of View		Masked Field of View		Full Field of View		Masked Field of View	
	Clear	Minimum	Clear	Minimum	Clear	Minimum	Clear	Minimum
1. Altitude Deviation	47.04	37.45	29.74	54.78	27.00	64.98	41.24	31.82
2. Bank Deviation	13.93	10.58	12.36	9.90	8.74	10.78	10.63	8.52
3. Elevator Power	1.16	2.16	1.73	1.66	2.08	2.05	2.24	1.98
4. Aileron Power	.47	.69	.37	.56	.62	.59	.43	.55
5. Rudder Power	.06	.06	.06	.04	.16	.05	.02	.08
6. Altitude Deviation	45.39	34.77	32.47	50.49	27.93	56.19	37.47	36.88
7. Downwind Score	57.58	69.38	69.30	62.55	76.03	48.41	68.67	71.35
8. Elevator Power	1.32	2.54	1.59	2.31	2.11	2.54	1.81	1.43
9. Aileron Power	1.04	1.29	.82	1.47	1.45	1.56	.96	1.11
10. Rudder Power	.14	.07	.11	.13	.07	.07	.09	.08
11. Bank Deviation	12.03	12.55	7.17	10.68	10.30	10.90	9.79	10.81
12. Airspeed Deviation	4.80	6.07	5.27	7.42	5.13	6.98	5.06	5.91
13. Elevator Deviation	1.20	1.85	1.29	1.72	2.00	1.52	1.37	2.06
14. Aileron Power	.93	.86	.66	.79	.72	1.03	.65	.77
15. Rudder Power	.43	.25	.58	.37	.64	.29	.39	.39
16. Altitude Deviation	1.46	1.50	.94	1.16	1.04	1.02	.88	1.16
17. Centerline Deviation	205.9	268.0	42.56	117.75	88.88	96.20	101.43	134.62
18. Airspeed Deviation	4.63	6.87	3.06	4.97	5.06	5.44	4.14	4.18
19. Final Score	12.22	11.28	16.98	9.55	7.54	5.90	14.00	4.74
20. Elevator Power	2.46	3.31	2.43	2.89	3.43	2.85	3.11	3.66
21. Aileron Power	2.14	2.09	1.60	2.29	1.73	2:29	1.58	1.88
22. Rudder Power	3.66	4.23	3.23	4.87	4.23	3.92	3.36	4.37
23. Total Score	77.06	76.32	77.05	73.47	75.14	76.94	79.19	76.63

Table 28. **Ceiling/Visibility by FOV by G-Seat Interaction Mean Ratings for the Takeoff, GCA and Overhead Pattern Maneuvers**

Takeoff

Ceiling Visibility		G-Seat Off		G-Seat On	
		Full FOV	Masked FOV	Full FOV	Masked FOV
	Clear	1 4.28	2 2.43	3 5.00	4 2.92
	Minimum	5 5.50	6 6.07	7 6.00	8 3.50

χ^2 crit = 4.91

Significant Cell Differences: None

GCA

Ceiling Visibility		G-Seat Off		G-Seat On	
		Full FOV	Masked FOV	Full FOV	Masked FOV
	Clear	1 6.33	2 2.83	3 3.75	4 2.46
	Minimum	5 3.45	6 6.70	7 5.92	8 4.54

χ^2 crit = 3.75

Significant cell Differences: 1-4, 2-6, 4-6

Overhead Pattern

Ceiling Visibility		G-Seat Off		G-Seat On	
		Full FOV	Masked FOV	Full FOV	Masked FOV
	Clear	1 4.65	2 2.80	3 4.06	4 3.32
	Minimum	5 5.56	6 5.34	7 5.52	8 4.60

χ^2 crit = 2.70

Significant Cell Differences: 2-5

maneuvers. Best performance was demonstrated under the G-seat off, masked FOV, and clear ceiling/visibility conditions for two of the three maneuvers. Generally, performance became poorer with the introduction of minimum C/V as well as introduction of the full FOV when considered in conjunction with G-seat on condition.

Interactions in the 3^4 Design. Environmental by environmental interactions were non-existent in the 3^4 design, as only one environmental variable was utilized. Environmental by system interactions and system by system interactions were nonsignificant as evaluated by the Wilks Lambda.

Subject Effects

Measures of subject differences were obtained on all five maneuvers. In both designs, these effects showed that each pilot had particular areas of expertise and sophistication; however, one of the three pilots was more consistently rank ordered in the first position than the other two. The significance for each of the subject effects is available in Appendix B where the MANOVA results for each of the maneuvers are listed.

IV. DISCUSSION OF RESULTS

Introduction

Before proceeding to the discussion proper, a cautionary note must be sounded. Because of the Air Force's urgent need for empirical data dealing with the material in this study, the real danger exists that overgeneralization or misgeneralization of the results may occur, thus leading to inappropriate or perhaps even incorrect decisions.

The experimental results of this study should be considered with the following facts in mind:

1. This study dealt only with experienced pilot performance so no generalizations should be made to the naive student training situation.

2. Performance in the study is reflected only in scores attained in the ASPT simulator and might in no way generalize to either performance in the aircraft, another simulator, or even to ASPT if it were programmed using different equations of flight.

3. Generalizations to the population from which the three subject pilots came are valid only to the extent that this small n is representative of the population of experienced T-37 instructor pilots. An attempt was made to partially control for this source of external invalidity through selection of the pilots used, but to the extent that the matching process was incomplete, the results could be misrepresentative.

4. The results of this study should probably not be generalized to maneuvers other than those flown during the experiment. The effects of motion, visual scene and G-seat are most likely quite task specific, and thus a particular set of design configurations that yielded no significant effect on the five maneuvers tested in this study could have produced different results had other tasks been tested.

5. The issue of training transfer to the aircraft cannot validly be addressed based upon the data collected in this study. Thus, although no motion performance was generally superior to performance in either 3 DOF or 6 DOF motion configurations, performance could be better simply because it is *easier* to fly the simulator without the task load added by a moving platform.

6. The basic purpose of the study was exploratory in nature. Hopefully, more definitive statements about the simulator design configurations issue can be made as follow-on study results are made available.

With the foregoing as a preamble, the remainder of this section will deal with an interpretation of the experimental findings. The general approach will parallel that used in the Results Section.

Environmental Variables

Part of the rationale for inclusion of environmental variables in this study was an attempt to provide face validity for the performance measurement algorithms as currently implemented in ASPT. Additionally, these variables provided a more realistic setting for the completion of each maneuver.

Overall, the environmental variables produced the anticipated results; that is, superior performance as demonstrated by system output, pilot input and derived scores was generally evidenced in "clear weather" conditions. Normally, as the weather conditions deteriorated, so did the pilots' performance. These results strongly indicate that the scoring algorithms were valid and that they operated in the intended manner. Specifically, only the turbulence variable failed to reach significance in *all* of the maneuvers where it was

evaluated. This was not surprising in that turbulence is always present to some degree in actual flight. The pilots, therefore, probabiy had the most experience in adapting to the disturbances produced by this variable.

System Variables

The variables of primary concern, platform motion, FOV and G-seat all evidenced significant impact upon the pilots' performance in the simulator. The first system configuration variable, platform motion, evidenced significant main effects on every maneuver investigated. This result provided evidence that although an individual may not be able to discern the operation or nonoperation of the motion platform, the status of the motion platform directly affected performance in the simulator. Generally, the pilots' performance was best under the no-motion condition and deteriorated with the addition of degrees of freedom of simulator movement. From a performance standpoint then, as the simulator became less stable, the pilots' scores became poorer, perhaps indicative of a more difficult task. Another possible explanation which accounts for the poorer performance under conditions of motion is that the motion platform may have provided inadequate or inappropriate cueing. The time lag between pilot input and system output may have contributed to the increased difficulty of achieving successful performance.

The G-seat significantly affected performance on two of the five maneuvers: the takeoff, and GCA maneuvers. One obvious characteristic common to the two maneuvers is the inherent lack of violent movements around the roll axis and to a lesser degree, the pitch axis. The overhead maneuver, the aileron roll, and to a limited extent, the slow flight maneuvers all incorporated rotational movement along the lateral axis. The lack of significance in the roll-oriented maneuvers may have been due to an engineering flaw which surfaced after the completion of data collection. It was discovered that the G-seat was functioning as if it were located at the center of gravity of the simulated T-37 aircraft rather than forward and slightly to the left of the CG as in the aircraft itself. This decreased the moment arm of the pilots' position relative to the longitudinal axis of the aircraft to near nonexistence. Thus, the G-seat may have been prevented from providing cues of the necessary magnitude. In those instances where the G-seat did produce significant effects, however, the performance was generally superior when the G-seat was functional as compared to when it was not. The differences between the seat pan only and full G-seat conditions in the aileron roll and slow flight maneuvers were inconsistent. Therefore, no interpretation should be drawn as to which was the superior condition.

The FOV variable evidenced significant differences in only one of the five maneuvers, aileron roll, and approached significance on one other maneuver, the overhead pattern. Inspection of the dependent variable values, however, consistently suggested that overall, the full FOV condition produced somewhat better performance. In spite of this, it seemed that on the basis of the overall nonsignificance, the additional cue information provided by the wide visual display was either not particularly vital or could be acquired from other sources (e.g., the instruments).

The performance of the aileron roll maneuver was superior under the full FOV condition as compared to no display and masked FOV display conditions. When the aileron roll and GCA's dependence upon precise rotational movement around the longitudinal axis of the aircraft was considered, it appeared that FOV is an important factor. In these cases, the wide FOV provided additional information regarding the bank position of the aircraft.

System by System Variable Interactions

All of the significant first order interactions of the system variables included the platform motion variable. This coupled with the relatively strong motion main effects attested to the power of this factor upon pilot performance. Consistently, the addition of some level of platform motion, either three or six DOF, in the presence of a full or a masked FOV, caused pilot performance to be degraded. This performance decrement was observed in the presence (or absence) of the G-seat as well. The deterioration in the scores was somewhat lessened by the presence of the G-seat or the masked FOV. Obviously, the G-seat was providing important cues to the pilot when used in conjunction with ASPT's platform motion system. But, it should not be forgotten that the best performance on the maneuvers was observed when neither motion cueing system was functioning. The better scores produced by the masked FOV, when used in conjunction with platform motion, is somewhat more difficult to explain. Possibly, the

limitations in the visual scene caused the pilot to seek the information from other sources, most likely the instrument panel. Instrument flight is commonly accepted to be a more precise mode of flight than is contact or visual flight.

System by Environmental Variable Interactions

The turbulence by motion interaction consistently demonstrated a synergistic effect between motion and turbulence variables. Both variables independently caused performance decrements when added in increasing amounts and when used in conjunction, these variables caused even greater deterioration. A simple explanation is that both the platform motion and the turbulence adversely affected the stability of the pilots' vehicle, thus causing more random fluctuation of the vehicle's flight path. The significant motion by turbulence interaction supported this argument.

Other significant interactions were the C/V by G-seat, C/V by FOV, and the second order C/V by FOV by G-seat interaction. These factors (C/V, FOV and G-seat) showed a surprisingly strong interactive potential. In the C/V by G-seat interaction in the GCA, best performance under clear weather conditions was evidenced when the G-seat was functional. However, when the weather deteriorated to minimums best performance occurred when the G-seat was inoperative. This interaction seemed to emphasize the differences between piloting processes in instrument and visual flight. Under IFR conditions, the pilot is trained to disregard kinesthetic information and relies upon the information provided by the instrument display. In visual flight, the pilot makes more use of "seat-of-the-pants" cues in controlling the vehicle.

The C/V by FOV interaction was somewhat more difficult to interpret. Under clear weather conditions, superior performance in the GCA was produced when the FOV was masked. Conversely, when the visibility was poor, the pilots performed better with the visual display at its full extent. It would appear that the additional information provided by the full FOV was beneficial in poor weather, but distracting in the clear conditions. This seems reasonable in that the cues necessary to perform a GCA in clear weather are largely concentrated directly ahead of the aircraft.

The C/V by FOV by G-seat interaction was very surprising due to the consistency and size of this second order effect. In all the maneuvers where this effect could have occurred, it was significant and large. Best performance occurred with clear C/V as compared to minimum C/V. This result remained constant across all conditions of FOV and G-seat. Similarly, the masked FOV consistently produced better performance than did the full FOV condition. The G-seat variable, however, did not demonstrate the consistency that the other variables manifested, and no interpretation is readily apparent when the G-seat contrasts are considered. One possible explanation for this phenomenon was that the visual information required to successfully complete the manuevers used in this study was concentrated directly forward of the aircraft, and that the additional information provided by the wide FOV was unnecessary. This, coupled with the information degradation caused by poor visibility, could have negatively affected the pilots' performance.

Subject Effects

Individual differences are not unusual in psychological research, and consistent significant subject effects were found throughout all of the maneuvers. These data strongly suggest that the pilots' patterns of vehicle control were quite individualistic. It also strongly implies that when presented new system or environmental conditions, pilots adapt to these changes in different ways. This evidence discredits the theory that all pilots would respond to simulator system configuration changes in like manner, or that system output measures are the only dependent variables of interest in simulation research.

Dependent Measures

An investigation of the dependent measures revealed basic differences in the sensitivity of the types of measures as a function of the simulator and environmental conditions presented to the pilot. Using the ratio of the non-error variance of each dependent measure on one effect to the remainder of the non-error variance, it was seen that if a change to the vehicle's environment occurred, the system output variables were most responsive. If changes to the vehicle's configuration occurred, the pilot input measures were most sensitive to the changes. This finding provided additional face validity for the dependent measurement set. The derived scores were equally distributed in their sensitivity to either environmental or configuration modification. Thus, if one wished to assess differences in performance occurring due to changes in simulator configuration, pilot input measures would seem to be most appropriate. On the other hand, if differences due to environmental alterations are sought, system output measures would seem to be most appropriate.

V. DISCUSSION OF METHOD

There are two aspects of the methodology selected for use in this study that deserve further discussion. The first issue deals with the design and analysis of the study; the second involves the types of measures used as dependent variables.

Study Design and Analysis

The problem faced at the conception of the study was multi-faceted. It was necessary to explore a large number of simulator configurations. The constraint was, however, to conduct the evaluation as economically as possible in terms of the number of subjects, the number of data measurement points and the amount of system time required. The selection of an economical multifactor design provided the vehicle that met these requirements.

Several trade-offs, therefore, were incurred as a result of the particular experimental designs used in this study. First, replication of measurement points became impossible. Although the lack of redundancy in the measurement process was expected to cause an increase in the variability of certain descriptive indices, it was outweighed by the confidence vested within the dependent measurement set.

Second, subject by treatment interactions, and third order interactions were unavailable for analysis due to the extremely small number of subjects. To counter part of this limitation, experienced pilots were selected as subjects to minimize the subject by treatment interactions. Also, past experience had shown that third and higher order interactions rarely contributed much to the non-error variance.

The results of this study substantiated the majority of the original assumptions. The major sources of variability were identified. Only one second order interaction reached a level of appreciable significance. All indications supported t[illegible]cy of this type of research design for the investigation of a multitude of independent variables upon task-experienced subjects. If, however, the research interest were in training paradigms, this type of design does not appear to provide the same benefits, largely due to the underlying assumption that subject by treatment interactions are of negligible importance, which is likely not true in training studies.

In this study a vast number of dependent variables were collected for the purpose of evaluating the measurement set. Therefore, the multi-variate approach was chosen. The MANOVA permitted the measurement set as a whole (taking into account all of the inter-correlations of the individual dependent measures) to be evaluated for its responsiveness to the independent variables. It should be pointed out that the analysis of this study solely from an univariate standpoint, would encounter two problems: (a) each dependent measure would have been assumed to be orthogonal (an obviously fallacious assumption), and (b) the Type I error rate would be enormously inflated. If this study had been conducted only at the univariate level, the Type I error rate would have been: (assuming $p < .05$ significant) $1 - (1-.05)^{57} = .947$, which is quite unacceptable.

Dependent Measures

The dependent measurement set used in this study was large. It was decided at the inception of this project that in order to fully describe the impact of the independent variables upon the pilot performance in the simulator, two areas must be measured: the aircraft's flight parameters and the work done by the pilot.

The results of the study clearly indicated that no one type of measure was sufficiently descriptive. Review of the non-error variances for the dependent measures illustrated that system output measures were sensitive to environmental changes and that pilot input measures were more responsive to system configuration changes.

This study provided basic information on the utility of the dependent measurement sets. A second study currently underway will provide additional data. Taking the two studies together should allow a reduction in the number of dependent measures required to describe pilot performance, yet not decrease the discriminability or explanatory properties of the measurement system.

VI. SUMMARY AND CONCLUSIONS

This study demonstrated the complexity of advanced simulation systems and reinforced the postulation that investigations stressing only one aspect of the simulation are somewhat naive. Research must be concerned not only with the particular system under question, but the task to be performed, the configuration of other portions of the simulation, and what types of measurements are employed. All of these factors interact

with each other and continually affect the resultant data.

In this study, each of the system configuration variables produced significant effects. The platform motion variable had a striking impact upon pilot performance. Almost invariably, the addition of platform motion cueing produced a concomitant decline in performance. Interest in this particular variable has prompted continuing research efforts in all major simulation devices including the ASPT. Further detailed aspects of motion cueing will be explored at AFHRL/FT.

Another system variable, the G-seat, although less dominant than the platform motion variable in its main effects, demonstrated a strong interactive potential. Interestingly, the interaction often occurred with a visually oriented independent variable.

The FOV variable showed tendencies to have extremely maneuver-specific effects. Since the magnitude of this effect changed as a function of maneuver and other system variable configurations, the implication is obvious: specifying an optimal FOV across several different maneuvers would be very difficult indeed. Considerable future research activity will be spent studying this particular system variable in the following areas: (a) FOV width and height, (b) content and density of visual information, and (c) texturing to produce accurate depth cues.

The interactions of significant impact in this study, as stated previously, confirmed the difficulty of attempting to isolate individual effects. These interactions, having been outlined in this study, are being pursued in a second study. The emergence of a strong second order interaction across all three maneuvers in the $3^3\ 2^3$ design indicates how completely multiple events affect pilot performance. This and other interactions must be further examined before definitive statements can be made on simulator design configurations.

The dependent variables used to measure performance in this study showed, as expected, that manipulation of the three environmental variable combinations produced changes in the system oriented dependent variables. Similarly, changes in the pilot input variables was concomitant with simulator configuration changes. Further research will be aimed at reducing the dependent measurement sets for certain maneuvers in order to more effectively and economically describe performance in the simulator.

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APPENDIX A: DESCRIPTION OF PERFORMANCE MEASUREMENT ALGORITHMS

The performance measurement algorithms used in this study subdivided each maneuver into several exercise segments. For each exercise segment, special computer programs, labelled "cases," were developed that determined simulator system conditions and defined the parameters to be measured in that segment. The operation of these cases may be described in the following manner. An initialization case set the simulator at the maneuver starting conditions. Intermediate cases executed a FORTRAN program with a 3.75 Hertz iteration rate. These were used to sample system outputs. A special case was provided which measured the pilot outputs at an iteration rate of 15 Hertz. An end point case froze the simulator when the end conditions for the maneuver were met.

Descriptions of the performance measurement algorithms for the five maneuvers are as follows:

Takeoff: The starting condition for the takeoff was on centerline, Runway (RW) 30L at Williams AFB, with the aircraft configured for takeoff. The pilot set the power at 100%, released brakes, and maintained runway heading using nose-wheel steering. When the airspeed reached 65 knots, the aircraft was rotated to hold approximately five degrees pitch. The rotation speed was allowed to increase in high crosswinds. The aircraft lifted off at approximately 90 knots. The pilot was instructed to maintain the takeoff attitude as he raised the gear and flaps.

After the flaps were raised, the pilot adjusted the pitch to smoothly climb and accelerate to 1,900 feet above mean sea level (MSL) and 196 knots while maintaining runway heading. During this initial climb, the pilot also maintained vertical velocity between 500 and 1,000 feet per minute (FPM). After passing 1,900 feet MSL, the pilot continued the climb at tech order airspeed and turned to intercept the 302 degree radial outbound from the Chandler VOR. The maneuver was terminated and the simulator frozen after passing 3,000 feet MSL.

GCA and Landing: The starting condition was 2,400 feet MSL, 300 degree heading, and 160 knots on an eight mile final for Runway 30C, Williams AFB. The pilot maintained starting conditions until the Cognitronics Voice System began giving GCA "controller" instructions. The pilot slowed to 110 knots and lowered the landing gear and flaps at the appropriate airspeeds. He followed the "controller" heading instructions to maintain course. At 4.5 miles, the pilot intercepted the glidepath. The controller then gave information on aircraft position above or below and left or right of glidepath.

When the pilot had the runway in sight, he should have made appropriate corrections to maintain the extended centerline and glidepath visually. The pilot was instructed to land on the runway centerline, approximately 1,000 feet down the runway. The maneuver was terminated on landing roll after airspeed decreased below 50 knots.

360° Overhead Pattern and Landing: The starting condition was 2,500 feet MSL, 300° heading, and 200 knots on four mile initial for RW 30L, Williams AFB. The pilot flew down initial, maintaining altitude, airspeed, and runway centerline. Approximately halfway down the runway, the pilot pitched out by reducing power to 50 or 60% rpm and made a steep turn to the left not to exceed 60° bank. After completing a 180° turn, he lowered the speedbrake and landing gear, maintaining 2,500 feet MSL and 120 knots minimum. Approximately 3/4 mile past the end of the runway, he lowered the flaps and started a descending turn to the left. He was to maintain 110 knots minimum and adjust the bank and descent rate so as to roll out on runway centerline at 1,700 feet MSL.

Once on final approach, the pilot was told to maintain 100 knots minimum and a constant glidepath. He adjusted pitch and power so as to touch down in the first 1,000 feet of the runway between 75 and 80 knots. The maneuver terminated when airspeed decreased below 50 knots during rollout.

Slow Flight: The starting condition was 12,000 feet MSL, 180° heading, and 100 knots. The pilot lowered speedbrake, landing gear, and full flaps while maintaining altitude and decreasing airspeed to 76 knots, approximately four knots above stalling airspeed. After holding airspeed for about 30 seconds, the Cognitronics Voice System directed him to start coordinated turns. The pilot performed shallow turns,

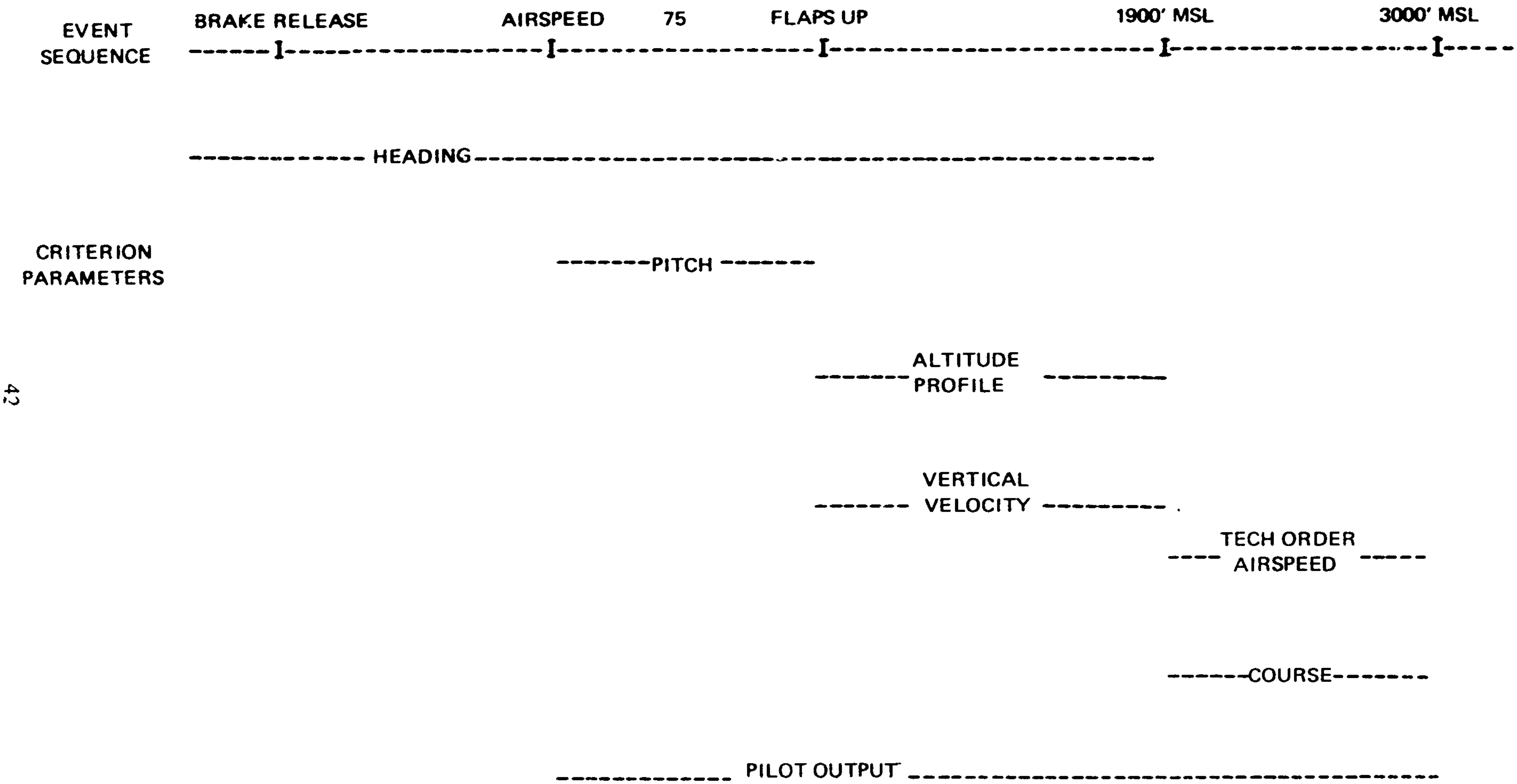

Figure A1. **Takeoff scoring sequence.**

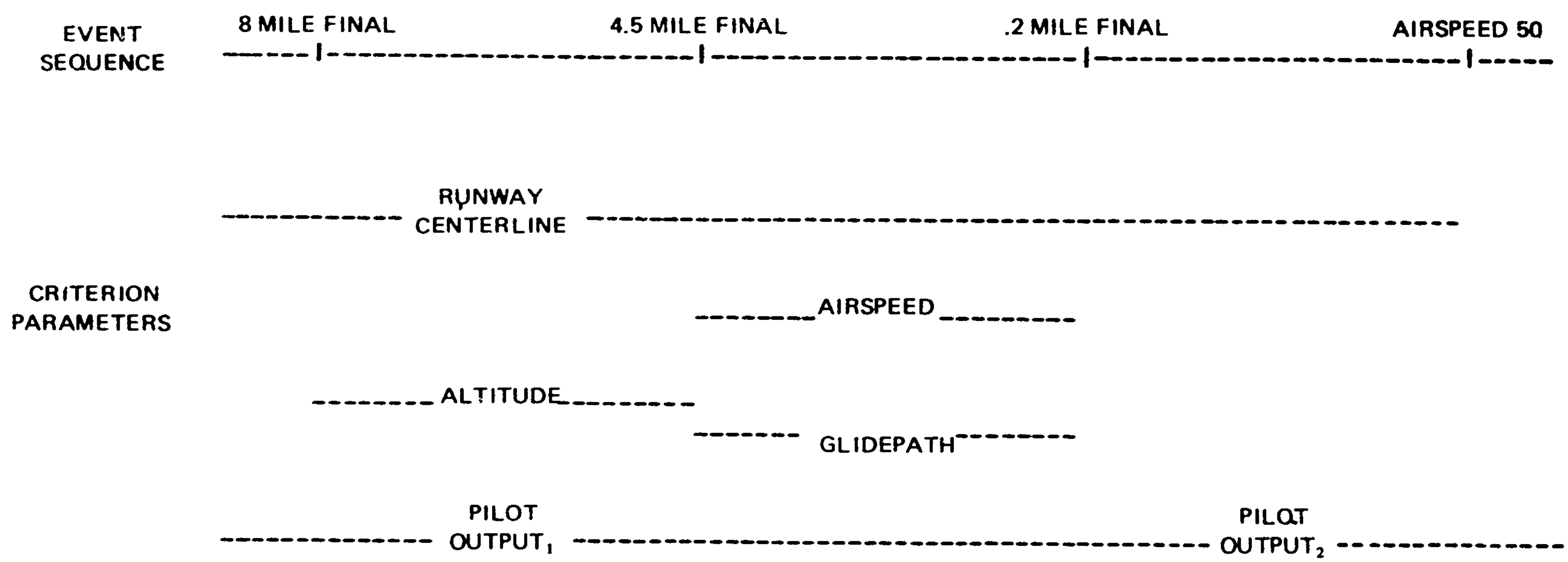

Figure A2. **GCA and landing scoring sequence.**

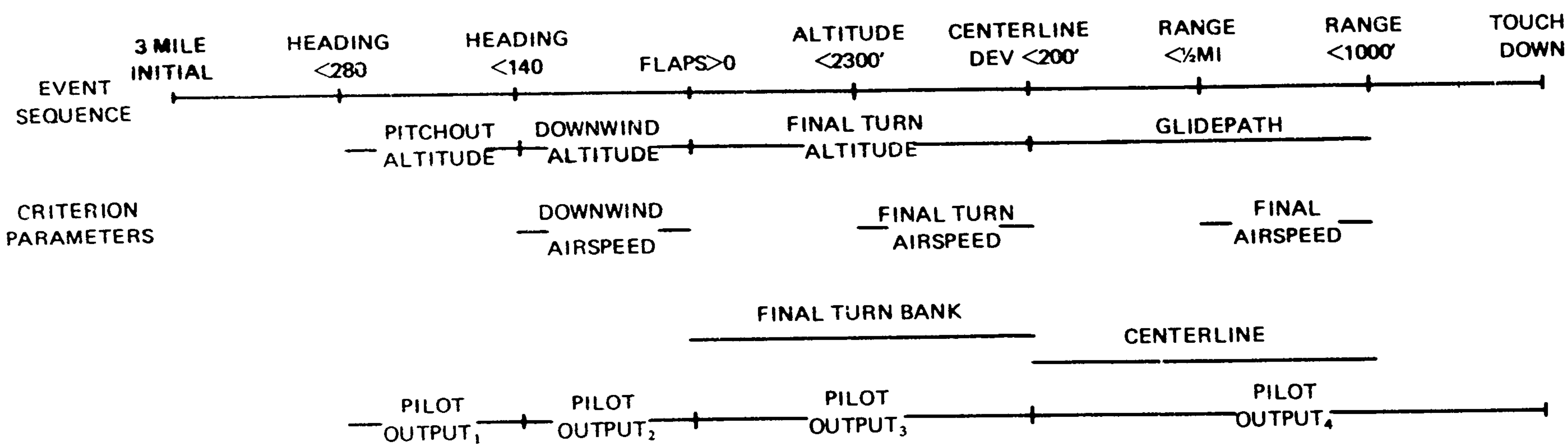

Figure A3. **360° Overhead pattern and landing scoring sequence.**

turing approximately 20° to each side of a central reference point or heading. After three turns were accomplished, the exercise was terminated.

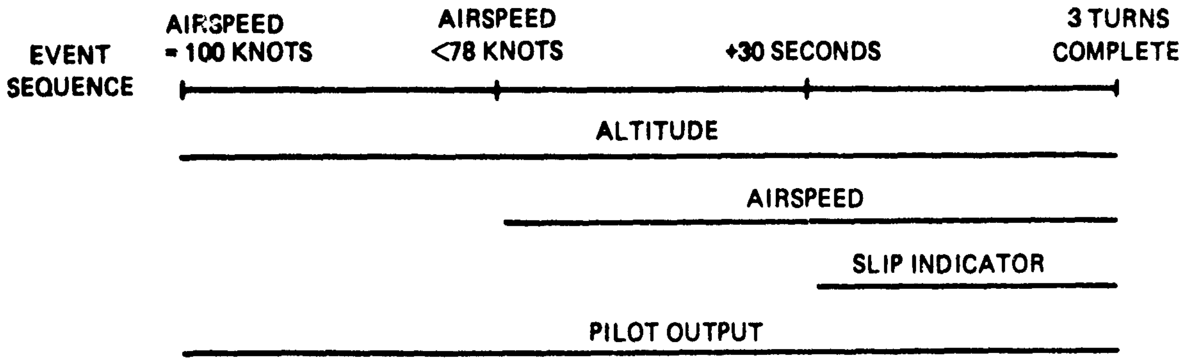

Figure A4. **Slow flight scoring sequence.**

Aileron Roll: The aileron roll was performed under two conditions:

1. *Instrument*. The starting condition was 15,000 feet, 160 knots, and 180° heading. The pilot lowered the nose to accelerate and set the power at 90%. He then raised the nose, so as to pass through level flight between 200 and 230 knots. He continued to bring the nose up smoothly with a wings level attitude until the nose was 25° above the horizon.

At this point, he started a roll in either direction, adjusting the roll rate as necessary so the wings were level in the inverted position as the nose passed through the horizon. He continued the roll and, after completing the maneuver in a nose-low, wings-level attitude, returned to level flight. At this point, the exercise was terminated.

2. *Contact*. The starting conditions, entry and airspeed and power setting were the same as in the instrument aileron roll. The entry pitch attitude was 20° to 30°. The roll was executed smoothly to maintain a constant roll rate. As the wings-level attitude was approached, aileron pressure was gradually released to roll out with the nose on the horizon. The exercise was terminated five seconds after the roll was complete.

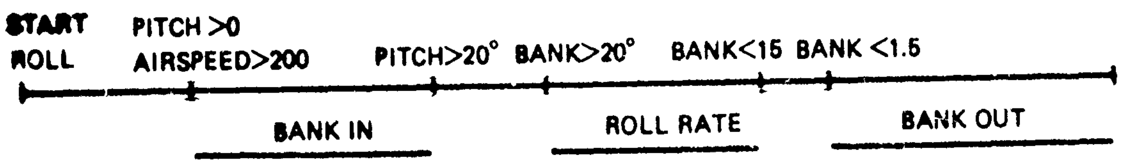

Figure A5. Aileron roll scoring sequence.

APPENDIX B: MULTIVARIATE ANALYSIS OF VARIANCE SOURCE TABLES (ALL MANEUVERS)

This appendix provides the original MANOVA output.

To facilitate understanding of this Appendix, the following guides are presented:

1. The order of the maneuvers is Takeoff, GCA, Overhead Pattern, Slow Flight, Aileron Roll.
2. Coding for independent variables was as follows:

$3^3 2^3$ Design	3^4 Design
A = Wind	A = Turbulence
B = Turbulence	B = Motion
C = Motion	C = Field of View
D = Ceiling/Visibility	D = G-Seat
E = Field of View	Blocks = Subjects
F = G-Seat	
Blocks = Subjects	

3. Coding for dependent variables is as follows:

Takeoff

Text Dependent Variable Name	Computer Dependent Variable Name
1. Heading Deviation	Head (2)
2. Pitch Deviation	To Att (2)
3. Course Deviation	Crs Dev (2)
4. Airspeed Deviation	KIAS (2)
5. Elevator Power	Elev Pwr (1)
6. Aileron Power	Ailr Pwr (1)
7. Rudder Power	Rudr Pwr (1)

GCA and Landing

1. Total Score	TT Score (1)
2. Touchdown Score	TD Score (1)
3. Altitude Deviation	AH (2)
4. Airspeed Deviation	KIAS (2)
5. Centerline Deviation	C L Dev (2)
6. Glidepath Deviation	G P Dev (2)
7. Elevator Power	Smooth 1 (7)
8. Aileron Power	Smooth 1 (8)
9. Rudder Power	Smooth 1 (9)
10. Elevator Power	Elev Pwr (1)
11. Aileron Power	Ailr Pwr (1)
12. Rudder Power	Rudr Pwr (1)

Overhead Pattern and Landing

1. Pitchout Altitude	ALT 1 (2)
2. Pitchout Bank	BNK 1 (2)
3. Elevator Power	Smooth 1 (7)
4. Aileron Power	Smooth 1 (8)
5. Rudder Power	Smooth 1 (9)
6. Downwind Altitude Deviation	ALT 2 (2)
7. Downwind Score	SCR 2 (2)
8. Elevator Power	Smooth 2 (7)
9. Aileron Power	Smooth 2 (8)
10. Rudder Power	Smooth 2 (9)

Overhead Pattern and Landing *(Continued)*

11. Final Turn Bank Deviation	BNK 3 (2)
12. Final Turn Airspeed Deviation	SPD 3 (2)
13. Elevator Power	Smooth 3 (7)
14. Aileron Power	Smooth 3 (8)
15. Rudder Power	Smooth 3 (9)
16. Glidepath Deviation	GSL 4 (2)
17. Centerline Deviation	CAE 4 (2)
18. Final Airspeed Deviation	SPD 4 (2)
19. Final Score	SCR 4 (1)
20. Elevator Power	Smooth 4 (7)
21. Aileron Power	Smooth 4 (8)
22. Rudder Power	Smooth 4 (9)
23. Landing Score	SCRL (1)

Slow Flight

1. Altitude Deviation	ALT (2)
2. Airspeed Deviation	KIAS (2)
3. Slip Indicator Deviation	Ball (2)
4. Total Score	Tot Scre (1)
5. Elevator Power	Elev Pwr (1)
6. Aileron Power	Ailr Pwr (1)
7. Rudder Power	Rudr Pwr (1)

Aileron Roll

1. Roll In Deviation	Bank in (2)
2. Roll Acceleration	Smooth 2 (4)
3. Roll Score	Roll rate (1)
4. Bank Out Deviation	Bankout (2)
5. Aileron Power (In)	Smooth 1 (8)
6. Aileron Power (Roll)	Smooth 2 (8)
7. Aileron Power (Out)	Smooth 3 (8)
8. Total Score	Totscore (1)

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR MANEUVER OVRHD PATTRN. TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	MEAN	A	B	C	D	E	F	AB	AC	AD
DEPENDENT VARIABLE..DF	1	2	2	2	1	1	1	4	4	2
20 ALT1(2) .	.3767+06	.1449+03	.1384+04	.4387+04	.6540+04	.1204+04	.5293+02	.4927+04	.2836+04	.6555+04
21 BNK1(2) .	.2466+05	.2683+04	.2353+02	.3952+02	.1166+03	.2304+02	.2213+03	.8925+02	.9405+02	.4338+01
22 SMOOTH1(7) .	.7695+03	.4135+02	.1895+01	.8159+01	.1398+01	.8050-01	.9194+01	.4606+01	.3424+01	.2692+01
23 SMOOTH1(8) .	.6278+02	.3133+01	.1564-01	.1925+01	.8861+00	.6809+00	.4149-01	.3494+00	.2862+00	.8252-01
24 SMOOTH1(9) .	.1129+01	.6382-01	.1159+00	.2371-01	.2395-01	.4454-01	.2527-01	.1692+00	.1500+00	.2769-01
25 ALT2(2) .	.3492+06	.1707+04	.1918+04	.4752+04	.4148+04	.1639+03	.7258+02	.1149+04	.8698+03	.9078+03
26 SCR2(1) .	.9599+06	.3056+04	.3083+04	.1430+04	.3015+04	.3133+04	.6366+02	.1236+04	.1292+04	.1171+04
27 SMOOTH2(7) .	.9393+03	.3857+01	.2556+01	.1301+02	.3018+02	.5186+00	.4272+01	.8387+01	.2924+01	.1210+01
28 SMOOTH2(8) .	.3193+03	.1512+01	.5446+00	.1700+02	.4462+01	.3159+01	.7209+00	.2959+01	.3485+00	.6263+00
29 SMOOTH2(9) .	.2158+01	.6256-02	.4019+00	.1268-01	.7881-02	.1307-01	.5241-01	.6946-01	.6363-01	.5877-01
30 BNK3(2) .	.2397+05	.1089+03	.2614+02	.4386+02	.1078+03	.1815+03	.1343+01	.6722+02	.7278+02	.1187+01
31 SPD3(2) .	.7357+04	.7717+03	.8490+01	.9736+01	.1259+03	.1565+01	.7380+00	.5806+01	.1539+02	.4471+02
32 SMOOTH3(7) .	.5756+03	.2669+02	.1388+01	.6590+01	.5607+01	.5391-01	.2730+01	.2325+01	.2593+01	.2217-01
33 SMOOTH3(8) .	.1408+03	.1672+01	.5214+00	.5310+01	.8525+00	.1505+01	.1675-01	.6743+00	.1053+01	.4142+00
34 SMOOTH3(9) .	.3841+02	.3727+01	.3289+00	.5041+00	.1895+01	.6382-01	.2270-01	.2433+01	.2087+00	.9525+00
35 GSL4(2) .	.2861+03	.8251+01	.1879+01	.2334+00	.9266+00	.2669+01	.3138+01	.2040+01	.5519+01	.2402+00
36 CAE4(2) .	.3760+07	.1697+06	.2702+05	.1810+04	.1067+06	.2330+06	.1534+06	.1450+06	.2002+06	.5571+04
37 SPD4(2) .	.4976+04	.3878+03	.8736+02	.8666+00	.7083+02	.1082+03	.1767+01	.1581+02	.6093+02	.1668+02
38 SCR4(1) .	.2284+05	.5274+04	.1028+03	.5742+03	.1253+04	.2335+03	.1076+04	.1335+04	.1168+04	.1324+04
39 SMOOTH4(7) .	.1972+04	.1245+02	.2846+01	.1060+02	.5496+01	.6085-02	.1291+02	.2260+02	.7329+01	.1285+01
40 SMOOTH4(8) .	.8242+03	.8081+02	.1155+01	.7283+01	.7576+01	.2757+01	.1362+01	.3830+01	.1174+01	.1810+01
41 SMOOTH4(9) .	.3438+04	.1124+04	.7542+02	.3102+02	.2839+02	.1513+00	.4035-01	.3194+02	.4804+02	.2663+01
42 SCRL(1) .	.1263+07	.8586+02	.1927 03	.3138+03	.8721+02	.2609+01	.5410+02	.7269+03	.9872+03	.3743+03
WILKS LAMBDA (WL)..	.0029	.1064	.6028	.3924	.5452	.6969	.6504	.4348	.3956	.7050
DF1................	23.0000	46.0000	46.0000	46.0000	23.0000	23.0000	23.0000	92.0000	92.0000	46.0000
DF2................	94.0000	188.0000	188.0000	188.0000	94.0000	94.0000	94.0000	374.5601	374.5601	188.0000
FO(APPROX FOR WL)..	1428.4308	8.4421	1.1769	2.4373	3.4100	1.7772	2.1967	.9534	1.0750	.7806
PROB(F>FO)..........	.0000	.0000	.2245	.0000	.0000	.0285	.0043	.6006	.3173	.8384

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR MANEUVER OVRHD PATTRN. TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	AE	AF	BC	BD	BE	BF	CD	CE	CF	DE
DEPENDENT VARIABLE..DF	2	2	4	2	2	2	2	2	2	1
20 ALT1(2) .	.1348+04	.1043+04	.5407+03	.1397+03	.5955+02	.1074+04	.1693+04	.1050+04	.2455+04	.5504+03
21 BNK1(2) .	.1191+02	.6778+02	.1992+03	.2082+02	.1361+02	.4965+01	.1022+01	.5293+01	.2473+03	.3547+02
22 SMOOTH1(7) .	.7383-01	.2179+01	.4330+01	.5552+01	.1672+01	.1687+00	.7640-02	.4556+01	.1064+02	.5671+01
23 SMOOTH1(8) .	.1992+00	.1231+00	.1892+01	.2558+00	.3376-02	.9681-01	.3733+00	.1247+01	.5607+00	.4712-01
24 SMOOTH1(9) .	.4191-01	.3039+00	.3337+00	.6273-01	.3817-01	.1822-01	.5926-01	.1579+00	.5109-01	.9336-01
25 ALT2(2) .	.2794+03	.4294+03	.2125+04	.1036+04	.2641+03	.2709+04	.3036+03	.1960+03	.1473+04	.1397+00
26 SCR2(1) .	.2258+04	.2651+03	.2003+04	.8302+02	.8363+03	.1998+04	.8476+03	.6376+03	.3387+04	.1019+02
27 SMOOTH2(7) .	.1234+01	.4014+01	.6556+01	.3296+00	.1255+01	.2620+01	.8220+00	.7271+00	.1940+02	.3302+00
28 SMOOTH2(8) .	.8384+00	.9467+00	.2166+01	.5069+00	.2076+01	.5259+01	.7903+00	.6798+01	.2346+01	.6350+00
29 SMOOTH2(9) .	.1781+00	.6914-01	.5699-01	.1778-01	.2052-01	.3222-01	.6392-01	.6860-02	.6064-03	.2555-01
30 BNK3(2) .	.4147+01	.9316+02	.8951+02	.5739+02	.5075+02	.1189+03	.6320+02	.5510+02	.1546+02	.3941+02
31 SPD3(2) .	.4023+02	.2107+02	.2313+03	.3841+02	.5422+01	.4456+01	.3392+02	.1218+02	.3494+01	.4636-01
32 SMOOTH3(7) .	.8362-02	.2471+01	.4365+01	.1955+00	.2047-01	.1850+01	.2506+01	.7697+00	.5209+01	.2942+01
33 SMOOTH3(8) .	.1595-01	.9959-02	.1195+01	.7144+00	.9709-01	.2389+00	.3284+00	.4398+00	.2088+00	.6740-03
34 SMOOTH3(9) .	.7065+00	.1055+00	.2900+01	.1158+01	.9053+00	.1567+01	.5211+00	.4373+00	.3377+01	.3554+00
35 GSL4(2) .	.1166+01	.1277+01	.7205+01	.4328+01	.1751+01	.2150+01	.6295+01	.2808+01	.2139+01	.8571+00
36 CAE4(2) .	.4749+05	.7166+05	.4158+06	.4534+06	.1547+04	.5336+05	.1132+06	.9139+05	.7554+05	.5122+04
37 SPD4(2) .	.5210+01	.1788+01	.1375+03	.4562+02	.8017+01	.3963+02	.1554+02	.2015+02	.5932+02	.1534+01
38 SCR4(1) .	.1573+03	.4911+03	.3006+04	.1583+04	.1950+04	.4888+03	.6783+02	.7510+03	.8394+03	.6719+03
39 SMOOTH4(7) .	.3289+01	.5709+00	.5436+01	.2170+00	.6937+00	.1640+01	.3605+00	.4437+01	.1111+02	.1864+01
40 SMOOTH4(8) .	.1956+01	.2104+01	.2649+01	.3719-01	.1925+01	.1500+01	.1041+01	.2276+01	.9340+00	.8172+00
41 SMOOTH4(9) .	.2123+02	.5576+01	.3165+02	.1012+02	.3816+02	.3592+01	.8996+01	.1333+02	.1037+01	.1899+02
42 SCRL(1) .	.3592+03	.8992+01	.1670+04	.1785+02	.2035+02	.1431+02	.3577+02	.2881+03	.8173+02	.1750+03
WILKS LAMBDA (WL)..	.6583	.7193	.3124	.6404	.6949	.6452	.6858	.6327	.4947	.7747
DF1...............	46.0000	46.0000	92.0000	46.0000	46.0000	46.0000	46.0000	46.0000	46.0000	23.0000
DF2...............	188.0000	188.0000	374.5601	188.0000	188.0000	188.0000	188.0000	188.0000	188.0000	94.0000
F0(APPROX FOR WL)..	.9503	.7319	1.3913	1.0200	.8157	1.0011	.8482	1.0513	1.7240	1.1889
PROB(F>F0).........	.5677	.8940	.0177	.4475	.7905	.4794	.7412	.3965	.0061	.2744

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5964

MANOVA FOR MANEUVER OVRHD PATTRN. TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	DF	EF	BLOCKS	ABD	ABE	ABF	ACD	ACE	ACF	ADE
DEPENDENT VARIABLE..DF	1	1	2	4	4	4	4	4	4	2
20 ALT1(2) .	.5797+03	.1213+04	.1593+04	.6922+03	.1880+04	.2890+04	.9472+03	.2380+04	.2022+04	.2970+04
21 BNK1(2) .	.1110+03	.1197+02	.3103+03	.6759+02	.4567+02	.4981+02	.2185+02	.4175+02	.8880+02	.5953+02
22 SMOOTH1(7) .	.4905+01	.1864-02	.4930+02	.4703+01	.5682+01	.6293+01	.6678+01	.8359+01	.1270+02	.3519+01
23 SMOOTH1(8) .	.3523+00	.7774-04	.9861+01	.4239+00	.6049+00	.6021+00	.3919+00	.1670+00	.1600+01	.2115-01
24 SMOOTH1(9) .	.3915-02	.3124-01	.9041-01	.1310+00	.1636+00	.2088+00	.4301+00	.2008+00	.1797+00	.1574+00
25 ALT2(2) .	.1387+04	.5333+03	.5620+04	.9684+03	.9340+03	.2830+04	.1477+04	.7143+02	.3355+02	.2856+04
26 SCR2(1) .	.1350+04	.1674+01	.1714+04	.2262+04	.1929+04	.3187+04	.1693+04	.8554+03	.1230+04	.2167+04
27 SMOOTH2(7) .	.2594+01	.6858+00	.2879+01	.1423+01	.1303+01	.3597+01	.7904+01	.313[illegible]+01	.7200+01	.5922+00
28 SMOOTH2(8) .	.1413+01	.2771+01	.4266+02	.2262+01	.3592+01	.6780+00	.2725+01	.1667+01	.3945+00	.6674+00
29 SMOOTH2(9) .	.7713-02	.1094-03	.4884+00	.2508+00	.1602+00	.1459-01	.1084+00	.7957-01	.8952-01	.2173-01
30 BNK3(2) .	.1964+02	.1272+03	.2362+03	.3530+02	.3766+02	.9248+02	.8923+02	.1072+03	.6563+02	.5360+02
31 SPD3(2) .	.1657+01	.2962+02	.3673+03	.3617+02	.5440+01	.2868+01	.1787+02	.1648+02	.4839+02	.1430+02
32 SMOOTH3(7) .	.2589+01	.1136-01	.7024+02	.6448+01	.4547+01	.3655+01	.1659+01	.1385+01	.4449+01	.1017+01
33 SMOOTH3(8) .	.4561+00	.1303-03	.1196+01	.3869+00	.3296+00	.1213+01	.1530+01	.5489+00	.1224+01	.3710-01
34 SMOOTH3(9) .	.9405-02	.5826+00	.2273+02	.1184+01	.2262+01	.5570+01	.2008+01	.1444+01	.2858+01	.8214+00
35 GSL4(2) .	.1403-03	.2430+01	.1312+02	.6590+01	.4568+01	.3314+01	.7658+01	.2359+01	.1626+01	.5288+00
36 CAE4(2) .	.3163+05	.4488+06	.2681+06	.4997+06	.1298+06	.1587+06	.2777+06	.1843+06	.2093+06	.4617+05
37 SPD4(2) .	.4686+02	.5661+01	.8204+02	.6187+02	.1865+02	.5234+02	.5565+02	.1364+02	.4588+02	.1861+01
38 SCR4(1) .	.2175+02	.1739+02	.5264+04	.1850+04	.2648+04	.6034+03	.1186+04	.2639+03	.4741+03	.7589+03
39 SMOOTH4(7) .	.5802+01	.2989+01	.1293+03	.8594+01	.4341+01	.6617+01	.1500+01	.6448+01	.1466+02	.1951+00
40 SMOOTH4(8) .	.1698+00	.1570+00	.5603+02	.3752+01	.5733+01	.1688+01	.1068+01	.3799+01	.6941+01	.6884+00
41 SMOOTH4(9) .	.7779+01	.1362+01	.2249+03	.5435+01	.3317+02	.7768+01	.7893+01	.1779+02	.1853+02	.1907+02
42 SCRL(1) .	.4323+02	.1470+03	.1075+04	.1671+03	.2785+03	.1378+03	.3611+02	.2557+03	.1423+03	.5226+01
WILKS LAMBDA (WL)..	.7166	.7466	.0496	.4283	.4369	.4451	.4645	.5167	.4085	.6135
DF1..............	23.0000	23.0000	46.0000	92.0000	92.0000	92.0000	92.0000	92.0000	92.0000	46.0000
DF2..............	94.0000	94.0000	188.0000	374.5601	374.5601	374.5601	374.5601	374.5601	374.5601	188.0000
FO(APPROX FOR WL)..	.6159	1.3872	14.2180	.9728	.9475	.9238	.8702	.7391	1.0333	1.1309
PROB(F>FO).........	.0563	.1382	.0000	.5532	.6150	.6715	.7878	.9595	.4080	.2807

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR MANEUVER OVRHD PATTRN. TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	ADF	AEF	BCD	BCE	BCF	BDE	BDF	BEF	CDE	CDF
DEPENDENT VARIABLE..DF	2	2	4	4	4	2	2	2	2	2
20 ALT1(2) .	.2783+03	.5087+04	.3936+04	.3326+04	.3566+04	.3491+03	.8102+03	.1128+04	.6160+03	.5538+03
21 BNK1(2) .	.2415+02	.3011+01	.3102+02	.5640+01	.2740+02	.2343+01	.1239+02	.3168+02	.2377+01	.5405+02
22 SMOOTH1(7) .	.6146+00	.3659+00	.8183+01	.1810+01	.2290+01	.3639+01	.7048+00	.1099+01	.3545+00	.1044+01
23 SMOOTH1(8) .	.3976-01	.2585+00	.5900+00	.1508+00	.4169+00	.9748-01	.2864-01	.8053-01	.1276-01	.1122-01
24 SMOOTH1(9) .	.6800-01	.8160-01	.4224-01	.2515+00	.1177+00	.3940-01	.1091+00	.1306+00	.3419-01	.3133+00
25 ALT2(2) .	.4330+03	.2406+04	.3997+04	.1547+04	.2837+04	.9645+03	.7600+03	.4519+03	.1182+04	.2466+03
26 SCR2(1) .	.3386+04	.3972+03	.2171+04	.1237+04	.3598+04	.8159+03	.5846+03	.2095+03	.3490+04	.8270+02
27 SMOOTH2(7) .	.2125+00	.1863+01	.6268+01	.3764+01	.1184+02	.1131+01	.4201-01	.3507+01	.2014+01	.4406+01
28 SMOOTH2(8) .	.1672+01	.2568+01	.2155+01	.1386+01	.3462+01	.3918+00	.1012+01	.2515+01	.1400+00	.1087+01
29 SMOOTH2(9) .	.1385-01	.1072+00	.2290+00	.2494+00	.1183+00	.3386+00	.9960-02	.1485-01	.3829-01	.1390+00
30 BNK3(2) .	.3264+02	.8660-01	.1216+03	.7140+02	.3565+02	.1628+02	.1271+02	.1624+03	.3970+02	.8061+02
31 SPD3(2) .	.1156+01	.1491+02	.1070+02	.1877+02	.4215+02	.2615+00	.2039+02	.1367+02	.2279+01	.4429+01
32 SMOOTH3(7) .	.4508+00	.4852+01	.2770+01	.2643+01	.2985+00	.9132+00	.8586+00	.2372+00	.6824+00	.7547+00
33 SMOOTH3(8) .	.6665+00	.1506+00	.1235+00	.6963+00	.5466+00	.1193+00	.8735+00	.5764+00	.2170-01	.5393+00
34 SMOOTH3(9) .	.1958+00	.1615+01	.2786+01	.8621+00	.1155+01	.1775+00	.5283+00	.1059+01	.5217+00	.7039+00
35 GSL4(2) .	.1863+00	.3857+01	.4344+01	.8739+01	.7624+01	.2989+01	.7124+01	.8096+00	.4135+01	.2372+01
36 CAE4(2) .	.5105+05	.2667+06	.2292+06	.3955+06	.2875+06	.1146+06	.1968+06	.1676+05	.1386+06	.3321+05
37 SPD4(2) .	.1615+02	.3613+02	.1201+03	.3765+02	.5238+02	.4864+01	.7042+01	.1103+02	.1298+02	.2946+01
38 SCR4(1) .	.6250+03	.5013+02	.1897+04	.8055+03	.3515+03	.9873+02	.1230+03	.6047+03	.1371+03	.2844+03
39 SMOOTH4(7) .	.9425+00	.3200+01	.1187+01	.6234+01	.1663+01	.1528+00	.1403+01	.1056+01	.5704+00	.6403+01
40 SMOOTH4(8) .	.1534+01	.1184+01	.1862+01	.9294+01	.3505+01	.2328+01	.8438+00	.1790+01	.2248+01	.5196+01
41 SMOOTH4(9) .	.1843+02	.5178-01	.1524+02	.3223+01	.7315+02	.2147+02	.1336+02	.1789+02	.2083+02	.2644+02
42 SCRL(1) .	.2493+03	.5271+03	.5346+03	.2876+03	.2489+03	.1104+03	.2460+01	.5302+03	.7470+01	.6190+02
WILKS LAMBDA (WL)..	.6900	.6645	.4379	.5102	.4593	.6996	.7904	.6595	.7542	.6624
DF1...............	46.0000	46.0000	92.0000	92.0000	92.0000	46.0000	46.0000	46.0000	46.0000	46.0000
DF2...............	188.0000	188.0000	374.5601	374.5601	374.5601	188.0000	188.0000	188.0000	188.0000	188.0000
FO(APPROX FOR WL)..	.8332	.9267	.9444	.7546	.8843	.7994	.5100	.9455	.6192	.9346
PROB(F>FO).........	.7644	.6090	.6275	.9481	.7591	.8135	.9959	.5760	.9718	.5952

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1   2**3 X 3**3   DESIGN - 5984

MANOVA FOR MANEUVER OVRHD PATTRN.   TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	CEF	DFF	ERROR
DEPENDENT VARIABLE...DF	2	1	116
20 ALT1(2) .	.7179+02	.2271+05	.7496+05
21 BNK1(2) .	.6708+02	.4563+02	.1694+04
22 SMOOTH1(7) .	.7122-01	.2396+01	.1328+03
23 SMOOTH1(8) .	.3243-01	.7257-01	.1477+02
24 SMOOTH1(9) .	.1425+00	.1232+03	.4949+01
25 ALT2(2) .	.7030+03	.1116+05	.5567+05
26 SCR2(1) .	.9857+03	.1169+05	.6207+05
27 SMOOTH2(7) .	.7776+00	.1570+01	.1324+03
28 SMOOTH2(8) .	.3870+01	.4334+00	.8339+02
29 SMOOTH2(9) .	.1145+00	.3677-01	.3276+01
30 BNK3(2) .	.1104+03	.2197+02	.2472+04
31 SPD3(2) .	.8756+01	.1160+02	.1077+04
32 SMOOTH3(7) .	.1621+01	.6577+01	.9055+02
33 SMOOTH3(8) .	.1203+00	.5230+00	.2637+02
34 SMOOTH3(9) .	.1080+01	.4762+00	.4657+02
35 GSL4(2) .	.9181-01	.5155-01	.1447+03
36 CAE4(2) .	.4377+05	.5523+03	.7270+07
37 SPD4(2) .	.1571-02	.1624-02	.1623+04
38 SCR4(1) .	.1971+04	.4356+01	.3653+05
39 SMOOTH4(7) .	.2165+01	.7801+01	.2422+03
40 SMOOTH4(8) .	.1427+01	.3418+01	.1190+03
41 SMOOTH4(9) .	.1326+01	.2207+00	.1[illegible]33+04
42 SCRL(1) .	.2130+03	.7844+01	.1326+05

WILKS LAMBDA (WL)..	.5973	.5866
DF1................	46.0000	23.0000
DF2................	188.0000	94.0000
FO(APPROX FOR WL)..	1.2[illegible]10	2.8802
PROB(F>FO).........	.1986	.0002

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY I 3**4 DESIGN - 5984

MANOVA FOR MANEUVER SLOW FLIGHT . TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	MEAN	A	B	C	D	AB	AC	AD	BC	BD
DEPENDENT VARIABLE..DF	1	2	2	2	2	4	4	4	4	4
1 ALT(2) .	.1560+06	.2212+04	.6139+04	.2460+04	.1876+04	.1263+04	.2141+04	.6036+03	.1414+04	.9310+03
2 KIAS(2) .	.2980+03	.5464+01	.8822+00	.2305+01	.5216-01	.1530+01	.1990+01	.2934+01	.6355+00	.1020+01
3 BALL(2) .	.4224+01	.1117-02	.1015-01	.1103-02	.4812-02	.1249-01	.2799-03	.4797-02	.3294-03	.7634-02
4 TOTSCRE(1) .	.7817+05	.2488+04	.2132+04	.3343+03	.2628+03	.3721+03	.7955+03	.6761+03	.2856+03	.1203+04
5 ELEV PWR(1) .	.4226+02	.1253+01	.9887+00	.5206+00	.2476+00	.5127+00	.1904+00	.8136+00	.3093+00	.1543+01
6 AILR PWR(1) .	.1510+02	.2275+00	.1393+01	.6397+00	.3788-01	.2264+00	.1430+00	.6382-01	.1036+01	.1090+00
7 RUDR PWR(1) .	.2922+00	.2025-02	.1413-01	.3614-02	.1469-02	.7537-02	.1264-01	.2158-01	.9126-02	.1116-01
WILKS LAMBDA (WL)..	.0010	.2164	.0675	.2661	.5389	.1660	.2532	.2026	.1469	.1025
DF1................	7.0000	14.0000	14.0000	14.0000	14.0000	28.0000	28.0000	28.0000	28.0000	28.0000
DF2................	8.0000	16.0000	16.0000	16.0000	16.0000	30.2666	30.2666	30.2666	30.2666	30.2666
FO(APPROX FOR WL)..	1134.7796	1.3141	3.2545	1.0727	.4139	.6977	.5013	.6022	.7589	.9521
PROB(F>FO).........	.0000	.2976	.0132	.4424	.9478	.8296	.9653	.9099	.7674	.5502

SOURCE.	CD	BLOCKS	ABC	ABD	ACD	BCD	ERROR
DEPENDENT VARIABLE..DF	4	2	8	8	8	8	14
1 ALT(2) .	.1427+04	.5697+04	.3459+04	.5520+04	.8952+03	.2242+04	.6913+04
2 KIAS(2) .	.2380+01	.4529+01	.2208+01	.1341+01	.3664+01	.5679+01	.5661+01
3 BALL(2) .	.2015-01	.5200-01	.1994-01	.5302-01	.5713-01	.1613-01	.9593-01
4 TOTSCRE(1) .	.4741+03	.2258+04	.2613+04	.1660+04	.2549+04	.1031+04	.1693+04
5 ELEV PWR(1) .	.1551+00	.1484+01	.3409+01	.1093+01	.1150+01	.1821+01	.2104+01
6 AILR PWR(1) .	.2792+00	.7634+00	.2709+00	.4030+00	.4694+00	.4314+00	.6813+00
7 RUDR PWR(1) .	.1065-01	.7753-02	.3481-01	.4793-01	.8023-01	.3380-01	.7948-01
WILKS LAMBDA (WL)..	.1180	.0662	.0200	.0262	.0463	.0414	
DF1................	28.0000	14.0000	56.0000	56.0000	56.0000	56.0000	
DF2................	30.2666	16.0000	48.3923	48.3923	48.3923	48.3923	
FO(APPROX FOR WL)..	.8746	3.2981	.9227	.8358	.6647	.6965	
PROB(F>FO).........	.6380	.0124	.6162	.7424	.9297	.9041	

FT MOTION/VISUAL/3-SEAT INTERACTIONS : STUDY 1 3**4 DESIGN - 5984

MANOVA FOR MANEUVER AILERON ROLL. TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	MEAN	A	B	C	D	AB	AC	AD	BC	BD
DEPENDENT VARIABLE..DF	1	2	2	2	2	4	4	4	4	4
8 BANKIN(2) .	.3421+03	.3981+01	.1261+02	.2483+01	.1390+01	.9336+01	.2368+01	.6537+01	.1584+02	.7752+01
9 SMOOTH2(4) .	.1297+05	.7027+02	.2438+03	.4143+03	.7531+01	.5272+02	.5675+02	.3101+02	.2260+03	.2118+03
10 ROLLRATE(1) .	.1201+06	.5143+03	.2453+03	.4233+03	.7614+03	.1477+04	.1714+04	.1908+03	.1032+04	.2084+04
11 BANKOUT(2) .	.9840+03	.2869-01	.1597+02	.4154+01	.2852+01	.1343+02	.1529+02	.8313+01	.6969+01	.4923+01
12 SMOOTH1(8) .	.2302+03	.2714+01	.1036+02	.1989+02	.5102+01	.6221+01	.8663+01	.1309+01	.1393+02	.1343+02
13 SMOOTH2(8) .	.1391+03	.2390+01	.3747+01	.1108+02	.1278+01	.4862+01	.6570+01	.3373+00	.7251+01	.7697+01
14 SMOOTH3(8) .	.1154+03	.3688+01	.5747+01	.5635+00	.3203+01	.4160+01	.7650+01	.3770+01	.3246+01	.1189+02
15 TOTSCORE(1) .	.6551+05	.2243+02	.3200+04	.1704+04	.6182+02	.2044+04	.6812+03	.4827+03	.2285+04	.7417+03
WILKS LAMBDA (WL)..	.0013	.1628	.0413	.0674	.2302	.0506	.0925	.0789	.0432	.0266
DF1...............	8.0000	16.0000	16.0000	16.0000	16.0000	32.0000	32.0000	32.0000	32.0000	32.0000
DF2...............	7.0000	14.0000	14.0000	14.0000	14.0000	27.4099	27.4099	27.4099	27.4099	27.4099
FO(APPROX FOR WL)..	676.6805	1.2938	3.4311	2.4965	.9489	1.0675	.7769	.8490	1.1520	1.4330
PROB(F>FO).........	.0000	.3171	.0127	.0463	.5444	.4340	.7552	.6741	.3554	.1703

SOURCE.	CD	BLOCKS	ABC	ABD	ACD	BCD	ERROR
DEPENDENT VARIABLE..DF	4	2	8	8	8	8	14
8 BANKIN(2) .	.7479+01	.4895+01	.1893+02	.3280+01	.6265+01	.1589+02	.3134+02
9 SMOOTH2(4) .	.1633+03	.1612+03	.1820+03	.6184+03	.2683+03	.3319+03	.6560+03
10 ROLLRATE(1) .	.2509+03	.1142+05	.4686+04	.2217+04	.3433+04	.2699+04	.6053+04
11 BANKOUT(2) .	.1839+02	.5342+01	.2426+02	.2856+02	.1530+02	.2212+02	.2782+02
12 SMOOTH1(8) .	.1096+02	.1860+02	.1501+02	.4562+02	.1978+02	.1647+02	.6017+02
13 SMOOTH2(8) .	.5440+01	.1149+01	.1319+02	.1970+02	.1135+02	.9134+01	.2503+02
14 SMOOTH3(8) .	.9932+01	.7852+01	.1566+02	.2834+02	.1460+02	.1172+02	.1400+02
15 TOTSCORE(1) .	.2352+04	.8233+04	.2797+04	.1232+04	.2727+04	.1912+04	.2504+04
WILKS LAMBDA (WL)..	.0349	.0109	.0018	.0127	.0077	.0085	
DF1...............	32.0000	16.0000	64.0000	64.0000	64.0000	64.0000	
DF2...............	27.4099	14.0000	46.8662	46.8662	46.8662	46.8662	
FO(APPROX FOR WL)..	1.2716	7.4982	1.4534	.8296	.9716	.9424	
PROB(F>FO).........	.2627	.0002	.0904	.7583	.5475	.5916	

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR MANEUVER TAKE-OFF . TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	MEAN	A	B	C	D	E	F	AB	AC	AD
DEPENDENT VARIABLE..DF	1	2	2	2	1	1	1	4	4	2
1 HEAD(2) .	.2479+04	.4478+03	.7098+00	.3768+00	.3094+02	.2721+01	.5936+00	.2222+01	.1333+01	.4991+01
2 TO ATT(2) .	.7239+03	.1566+01	.1611+01	.2389+01	.3496+00	.1499+00	.3632+01	.5916+00	.1882+00	.181[illegible]
3 CRS DEV(2) .	.2662+03	.5052+01	.2111+01	.3832+01	.3881+00	.2964+01	.1660+01	.3131+01	.1094+02	.3945+01
4 KIAS(2) .	.5554+04	.2901+02	.1022+02	.1073+03	.4187+03	.4348+02	.6803+02	.3310+02	.2784+02	.9917+01
5 ELEV PWR(1) .	.1408+04	.1628+01	.3194+01	.1468+01	.2180+01	.6146+00	.1357+01	.2900+01	.9156+00	.2390+00
6 AILR PWR(1) .	.1325+03	.4998+01	.7946+00	.5378+01	.8734+00	.1559+01	.3762+00	.1375+01	.5729+00	.5902-01
7 RUDR PWR(1) .	.3817+02	.2421+01	.4835+00	.7194+00	.1836-01	.1280-01	.6190+00	.8539+00	.2859+00	.1430+00
WILKS LAMBDA (WL)..	.0139	.1488	.7885	.6165	.6189	.8633	.7127	.7461	.7961	.8456
DF1................	7.0000	14.0000	14.0000	14.0000	7.0000	7.0000	7.0000	28.0000	28.0000	14.0000
DF2................	110.0000	220.0000	220.0000	220.0000	110.0000	110.0000	110.0000	398.0328	398.0328	220.0000
FO(APPROX FOR WL)..	1116.0026	25.0205	1.9827	4.3000	9.6774	2.4877	6.3334	1.2028	.9281	1.3742
PROB(F>FO).........	.00[illegible]	.0000	.0202	.0000	.0000	.0207	.0000	.2223	.5738	.1673

SOURCE.	AE	AF	BC	BD	BE	BF	CD	CE	CF	DE
DEPENDENT VARIABLE..DF	2	2	4	2	2	2	2	2	2	1
1 HEAD(2) .	.1004+01	.1060+01	.7898+01	.1203+01	.6676-01	.4256-01	.2809+00	.4935+01	.1745+01	.7514-01
2 TO ATT(2) .	.4208+00	.2655+00	.5134+01	.4405+00	.4571+00	.7467+00	.6668+00	.1756+01	.5191+01	.4516-01
3 CRS DEV(2) .	.5138+01	.2256+01	.9662+00	.1035+01	.1728+01	.2529+01	.2863+00	.5127+01	.6120+01	.4728-01
4 KIAS(2) .	.3668+02	.9503+01	.1169+03	.1758+02	.9825+00	.2568+02	.6047+02	.3895+02	.2319+02	.4433+01
5 ELEV PWR(1) .	.1347+00	.5885+00	.2769+01	.3237+00	.1015+00	.5397+00	.5837+00	.2475+01	.1219+01	.3925-03
6 AILR PWR(1) .	.1787+00	.1671+00	.9034+00	.4441-01	.1661-02	.1934+00	.4284+00	.1403+01	.3186+00	.2961+00
7 RUDR PWR(1) .	.1670-01	.7048-01	.5482+00	.6170-02	.4170-01	.8967-01	.4397-01	.1692+00	.8124+00	.5727+00
WILKS LAMBDA (WL)..	.8776	.9304	.6393	.9480	.9647	.8632	.9095	.7879	.6673	.9352
DF1................	14.0000	14.0000	28.0000	14.0000	14.0000	14.0000	14.0000	14.0000	14.0000	7.0000
DF2................	220.0000	220.0000	398.0328	220.0000	220.0000	220.0000	220.0000	220.0000	220.0000	110.0000
FO(APPROX FOR WL)..	1.0597	.5768	1.8778	.4250	.2850	1.1989	.7633	1.9887	3.5227	1.0897
PROB(F>FO).........	.3959	.8816	.0050	.9657	.9951	.2775	.7081	.0197	.0000	.3749

SOURCE.	DF	EF	BLOCKS	ABD	ABE	ABF	ACD	ACE	ACF	ADE
DEPENDENT VARIABLE..DF	1	1	2	4	4	4	4	4	4	2
1 HEAD(2) .	.7666-03	.1325+00	.1342+02	.1167+01	.2923+00	.1134+01	.3775+01	.1387+01	.1931+01	.1209+00
2 TO ATT(2) .	.4781-02	.55[illegible]9+00	.2670+02	.1613+01	.1451+01	.3512+01	.2134+01	.1079+00	.2347+00	.1010+01
3 CRS DEV(2) .	.6518+00	.9383+01	.5931+01	.1899+01	.5448+01	.4247+01	.2533+01	.6176+01	.1176+02	.8099+00
4 KIAS(2) .	.3886+01	.5156+01	.3954+03	.7319+02	.2913+02	.6401+02	.1712+02	.3278+02	.3403+02	.2179+01
5 ELEV PWR(1) .	.4109+01	.4796+00	.8937+00	.4041+01	.2210+01	.3235+00	.3263+01	.5414+01	.6392+00	.3122+01
6 AILR PWR(1) .	.1169-01	.1856-02	.3180+01	.9261+00	.7877+00	.8891+00	.4216+00	.1143+01	.1027+01	.2311+00
7 RUDR PWR(1) .	.2199-02	.2439-02	.1575+01	.7462+00	.4077+00	.3402+00	.5443+00	.6021+00	.2012+00	.4809-01
WILKS LAMBDA (WL)..	.8993	.8999	.2865	.7530	.8033	.7837	.7979	.7396	.7775	.8798
DF1................	7.0000	7.0000	14.0000	28.0000	28.0000	28.0000	28.0000	28.0000	28.0000	14.0000
DF2................	110.0000	110.[illegible]	220.0000	398.0328	398.0328	398.0328	398.0328	398.0328	398.0328	220.0000
FO(APPROX FOR WL)..	1.7602	1.7474	13.6419	1.1635	.8901	.9940	.9186	1.2403	1.0275	1.0391
PROB(F>FO).........	.1025	.1053	.0000	.2616	.6303	.4766	.5879	.1890	.4291	.4156

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR MAX LEVEL TAKE-OFF • TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	ADF	AEF	ACD	BCE	BCF	BDE	BDF	BEF	CDE	CDF
DEPENDENT VARIABLE...DF	2	2	4	4	4	2	2	2	2	2
1 HEAD(2) .	.9007+00	.1995+01	.5862+01	.3949+01	.9439+00	.5631+00	.6540+01	.2221+01	.3482+01	.1336+01
2 TO ATT(2) .	.1054+01	.4112+00	.3585+00	.1423+01	.7078+00	.6810+00	.1001+01	.9501+00	.1414+01	.2301-01
3 CMS LEV(2) .	.2768+00	.7155+01	.5978+01	.1381+01	.9812+00	.5409+00	.7937+00	.2187+01	.1292+00	.2140+00
4 KIAS(2) .	.8240+01	.4343+01	.8140+02	.2253+02	.1207+03	.2428+00	.6879+02	.4406+01	.8790+01	.1845+02
5 ELEV PAR(1) .	.4837-02	.3190+00	.1622+01	.4442+01	.1028+01	.1004+00	.3464+00	.3546+01	.2168-01	.7874+00
6 AILR PAR(1) .	.5767+00	.1219+01	.7334+00	.2649+00	.5539-01	.7511-01	.8098+00	.4621+00	.1423+00	.2011+01
7 RUDR PAR(1) .	.1359+00	.9416-01	.3103+00	.6712+00	.1983+00	.1695-01	.9962-01	.1660+00	.1276+00	.2889+00
WILKS LAMBDA (WL)..	.9007	.8349	.7643	.8099	.8550	.9551	.8269	.8498	.9088	.8558
DF1................	14.0000	14.0000	28.0000	28.0000	28.0000	14.0000	14.0000	14.0000	14.0000	14.0000
DF2................	220.0000	220.0000	398.0328	398.0328	398.0328	220.0000	220.0000	220.0000	220.0000	220.0000
FO(APPROX FOR WL)..	.8444	.9912	1.1005	.8558	.6314	.3649	1.5671	1.3327	.7695	1.2725
PROB(F>FO).........	.6268	.4632	.3334	.6804	.9297	.9830	.0901	.1896	.7015	.2260

SOURCE.	CEF	DEF	ERROR
DEPENDENT VARIABLE...DF	2	1	116
1 HEAD(2) .	.3926+00	.2064-02	.1072+03
2 TO ATT(2) .	.1216+01	.1426+00	.4205+02
3 CMS LEV(2) .	.3874+01	.4529-01	.9483+02
4 KIAS(2) .	.5349+01	.1316+03	.1363+04
5 ELEV PAR(1) .	.6407+00	.7148-02	.5423+02
6 AILR PAR(1) .	.4118+00	.1129+01	.2182+02
7 RUDR PAR(1) .	.4942-01	.1166-01	.1119+02
WILKS LAMBDA (WL)..	.8617	.8670	
DF1................	14.0000	7.0000	
DF2................	220.0000	110.0000	
FO(APPROX FOR WL)..	1.2139	2.4114	
PROB(F>FO).........	.2664	.0246	

FT MOTION/VISUAL/G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR MANEUVER GCA TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	MEAN	A	B	C	D	E	F	AB	AC	AD
DEPENDENT VARIABLE..DF	1	2	2	2	1	1	1	4	4	2
8 TT SCORE(1) .	.1324+06	.1820+03	.5059+03	.7713+03	.1021+04	.1872+02	.3545+03	.2392+03	.4809+03	.6567+02
9 TD SCORE(1) .	.1509+07	.2399+04	.5029+03	.8679+02	.3905+03	.8848+02	.3751+02	.8294+03	.5859+03	.9528+02
10 ALT(2) .	.3385+06	.2888+03	.3166+04	.4723+04	.1458+03	.1261+04	.4200+04	.7911+03	.9567+03	.1894+04
11 KIAS(2) .	.1448+04	.8097+01	.4386+02	.1202+02	.3860-02	.3352+01	.2760+01	.4374+01	.5457+00	.6402+00
12 C L DEV(2) .	.2233+07	.3901+04	.1314+04	.3055+04	.9521+04	.1155+04	.8762+04	.1303+04	.4429+04	.5721+02
13 G P DEV(2) .	.2793+06	.8368+03	.4724+03	.1958+02	.3580+03	.2982+03	.4143+03	.5463+03	.3239+03	.6249+03
14 SMOOTH1(7) .	.4349+02	.2669-01	.1341+01	.1664+01	.8741-01	.1218+00	.1183+00	.3847-01	.1912+00	.2118-01
15 SMOOTH1(8) .	.4653+02	.3500+00	.8225+00	.5309+01	.3168-04	.9377+00	.7485-01	.9199+00	.4215+00	.2626-01
16 SMOOTH1(9) .	.2547+01	.3967+00	.2131+00	.3877-01	.7724-05	.8026-02	.4491-02	.1258+00	.9751-01	.1032+00
17 ELEV PWR(1) .	.3806+04	.8313+02	.3423+02	.3094+02	.1506+01	.6121-01	.1107+02	.2957+02	.2062+02	.1973+01
18 AILR PWR(1) .	.6050+03	.4404+02	.1241+01	.1688+02	.3738+01	.1770+01	.3477-01	.9434+00	.3357+01	.2641+01
19 RUDR PWR(1) .	.1451+05	.8956+04	.1058+03	.2159+03	.1297+00	.6042+02	.3942+02	.2100+02	.2524+03	.1866+03
WILKS LAMBDA (WL)..	.0044	.1743	.5235	.3699	.7797	.7295	.6957	.5748	.6106	.7553
DF1................	12.0000	24.0000	24.0000	24.0000	12.0000	12.0000	12.0000	48.0000	48.0000	24.0000
DF2................	105.0000	210.0000	210.0000	210.0000	105.0000	105.0000	105.0000	406.5097	406.5097	210.0000
FO(APPROX FOR WL)..	1993.5117	12.2112	3.3429	5.6367	2.4729	3.2439	3.8276	1.3094	1.1571	1.3184
PROB(F>FO).........	.0000	.0000	.0000	.0000	.0069	.0005	.0001	.0887	.2282	.1543

SOURCE.	AE	AF	BC	BD	BE	BF	CD	CE	CF	DE
DEPENDENT VARIABLE..DF	2	2	4	2	2	2	2	2	2	1
8 TT SCORE(1) .	.4094+02	.2049+03	.5860+03	.2384+03	.4685+02	.7389+02	.5257+02	.5490+02	.3305+02	.6312+03
9 TD SCORE(1) .	.4689+03	.2833+03	.2822+03	.1675+03	.1643+02	.1913+03	.4653+01	.2608+03	.3927+03	.2137+03
10 ALT(2) .	.2649+03	.1944+04	.2241+04	.6354+02	.2248+03	.4929+03	.1640+03	.3051+02	.4632+03	.3049+04
11 KIAS(2) .	.5615+01	.1766+01	.7910+01	.3672+00	.1977+01	.1948+01	.5476+00	.6450+00	.1294+01	.3031+01
12 C L DEV(2) .	.8261+03	.2001+04	.4135+04	.2124+04	.7284+03	.1128+04	.9683+01	.2237+03	.1352+04	.6431+04
13 G P DEV(2) .	.5707+03	.1245+03	.2963+03	.3862+03	.3883+03	.2484+03	.1672+03	.5801+03	.5176+03	.3725+03
14 SMOOTH1(7) .	.7596-01	.9197-01	.4876+00	.2725-02	.1128+00	.1419-01	.3977-01	.3863-01	.1450+00	.4476-01
15 SMOOTH1(8) .	.1780+00	.5003-01	.6642+00	.6006-01	.5872-01	.5883-02	.1131+00	.1410+01	.1603+00	.4611+00
16 SMOOTH1(9) .	.4212-01	.3571-02	.1013+00	.8245-02	.7688-01	.1476-01	.2965-01	.1849+00	.6137-02	.1169-04
17 ELEV PWR(1) .	.1089+02	.6854+01	.9662+01	.1396+02	.6572+01	.1712+02	.2529+02	.4156+02	.5293+01	.2964+02
18 AILR PWR(1) .	.1374+01	.3728+01	.1882+02	.1438+01	.2998+01	.2018+01	.2297+01	.8158+01	.1570+01	.4894+01
19 RUDR PWR(1) .	.1557+03	.7959+02	.2696+03	.1148+03	.4595+02	.4019+02	.1437+03	.3280+03	.1030+03	.1959+03
WILKS LAMBDA (WL)..	.8182	.7581	.4801	.8432	.8401	.8511	.8261	.5850	.8322	.7748
DF1................	24.0000	24.0000	48.0000	24.0000	24.0000	24.0000	24.0000	24.0000	24.0000	12.0000
DF2................	210.0000	210.0000	406.5097	210.0000	210.0000	210.0000	210.0000	210.0000	210.0000	105.0000
FO(APPROX FOR WL)..	.9235	1.2993	1.7769	.7790	.7964	.7344	.8773	2.6902	.8416	2.5438
PROB(F>FO).........	.5700	.1667	.0017	.7609	.7393	.8127	.6329	.0001	.6809	.0055

[illegible] ACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR [illegible] BCA . TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	DF	[illegible]F	BLOCKS	ABD	ABE	ABF	ACD	ACE	ACF	ADE
DEPENDENT VARIABLE...DF	1	1	2	4	4	4	4	4	4	2
[illegible]TT SCORE(1) .	.33[illegible]6+02	[illegible]	.6169+04	.4003+03	.8871+03	.4572+03	.3640+03	.4075+03	.2995+03	.3998+03
[illegible] TO SCORE(1) .	.1310+03	[illegible]+03	.7627+02	.7608+03	.5560+02	.6724+03	.7803+03	.1021+04	.1201+04	.1821+03
10 ALT(2) .	.5525+04	[illegible]594+[illegible]	.1076+05	.1978+04	.7139+03	.7481+03	.5157+03	.6510+03	.8084+03	.6615+02
11 KIAS(2) .	.1277+[illegible]	.[illegible]738-01	.5881+02	.8267+00	.3060+01	.4649+01	.2709+01	.4651+01	.2532+01	.7120+00
12 C L DEV(2) .	.3391+03	.2051+02	.1125+06	.4646+04	.4309+04	.4658+04	.1373+04	.2813+03	.8405+03	.1064+04
13 G P DEV(2) .	.8606+02	.1116+02	.4422+04	.6936+03	.3662+03	.1377+04	.6194+03	.2428+02	.2870+02	.2020+03
14 SMOOTH1(7) .	.2263-02	.4743-02	.8345+00	.9204-01	.4934+00	.2237+00	.2171+00	.1268+00	.4184-01	.5906-01
15 SMOOTH1(8) .	.8407-01	.23[illegible]9-01	.0663+01	.3915+00	.8556+00	.1415+00	.2336+00	.5180+00	.8369-01	.1012+00
16 SMOOTH1(9) .	.9823-02	.7[illegible]49-03	.7955+00	.5703-01	.1708+00	.1751-01	.6957-01	.1899+00	.1045-01	.2105-02
17 ELEV P[illegible](1) .	.3535+01	.[illegible]242+02	.2620+02	.3045+02	.4301+02	.3530+02	.3993+02	.1864+02	.9860+01	.2858+02
18 AILR P[illegible](1) .	.9659-02	.[illegible]499+01	.6707+02	.8479+01	.3641+01	.1235+01	.1962+01	.1001+02	.3204+01	.8124+00
19 RUDR P[illegible](1) .	.3357+01	.2[illegible]06+02	.1163+04	.2690+03	.1072+03	.2813+03	.1233+03	.8912+02	.1833+03	.1381+03
WILKS LAMBDA (L)..	.7744	.9[illegible]73	.0497	.6179	.5835	.6485	.6699	.5717	.7210	.7822
DF1.................	12.[illegible]	12.[illegible]	24.0000	48.0000	48.0000	48.0000	48.0000	48.0000	48.0000	24.0000
DF2.................	1[illegible]5.[illegible]	1[illegible]5.[illegible]	210.0000	406.5097	406.5097	406.5097	406.5097	406.5097	406.5097	210.0000
F(APPROX FOR L)..	2.5434	.7[illegible]92	30.5101	1.1275	1.2712	1.0077	.9283	1.3228	.7504	1.1437
PR(F>F0).........	.0[illegible]55	.6615	.0000	.2674	.1147	.4632	.6117	.0809	.8891	.2989

SOURCE.	ADF	AEF	BCD	BCE	BCF	BDE	BDF	BEF	CDE	CDF
DEPENDENT VARIABLE...DF	2	2	4	4	4	2	2	2	2	2
[illegible]TT SCORE(1) .	.99[illegible]8+0[illegible]	.13[illegible]4+03	.4482+02	.7726+02	.9048+02	.9326+03	.9686+02	.1133+02	.7892+02	.1970+03
[illegible] TO SCORE(1) .	.2076+03	.1483+03	.3800+03	.3435+03	.2550+03	.5412+02	.2768+03	.2840+03	.5088+03	.3671+03
10 ALT(2) .	.1264+03	.1671+04	.5445+03	.8135+03	.1492+04	.6185+03	.1262+04	.7069+03	.1040+04	.8691+03
11 KIAS(2) .	.4421+01	.7628+00	.1250+01	.1328+01	.4755+00	.3870+00	.3354+01	.8411+00	.4887+01	.3049+01
12 C L DEV(2) .	.1248+04	.2569+04	.7132+03	.3017+04	.4375+04	.3364+04	.2192+04	.5272+03	.4590+04	.1403+04
13 G P DEV(2) .	.1160+03	.[illegible]855+03	.1827+04	.6068+03	.7426+03	.1857+03	.7567+02	.3112+03	.3816+03	.1021+03
14 SMOOTH1(7) .	.6300-01	.4322-01	.1282+00	.2660+00	.5957-01	.1798+00	.1563-01	.3961-01	.1185+00	.7753-01
15 SMOOTH1(8) .	.6513-01	.1[illegible]6-01	.2556+00	.1586+00	.1434-01	.1381+00	.8207-01	.6899-01	.2400+00	.6975-01
16 SMOOTH1(9) .	.7[illegible]2-02	.1958-01	.1401+00	.1686+00	.1259-01	.6762-01	.1038-01	.1357-01	.5355-01	.1805-01
17 ELEV P[illegible](1) .	.2709+02	.1168+01	.1477+02	.8479+01	.1312+02	.1561+02	.1239+02	.1527+02	.1585+02	.1643+01
18 AILR P[illegible](1) .	.1633+01	.4116+01	.2521+01	.2862+01	.6280+01	.7246+00	.3482+01	.2601+01	.3094+01	.4097+01
19 RUDR P[illegible](1) .	.9675+02	.2213+02	.5397+02	.1040+03	.7072+02	.1542+03	.3009+02	.4512+02	.6754+02	.2672+02
WILKS LAMBDA (L)..	.7[illegible]7[illegible]	.8275	.6593	.6330	.7454	.7615	.8333	.8349	.7641	.8475
DF1.................	24.[illegible]	24.[illegible]	48.0000	48.0000	48.0000	24.0000	24.0000	24.0000	24.0000	24.0000
DF2.................	21[illegible]	210.[illegible]	406.5097	406.5097	406.5097	210.0000	210.0000	210.0000	210.0000	210.0000
F(APPROX FOR L)..	1.0[illegible]	.[illegible]7	.9670	1.0675	.6713	1.2770	.8353	.8261	1.2600	.7549
PR(F>F0).........	.4[illegible]	.6446	.5388	.3588	.9547	.1823	.6893	.7013	.1949	.7896

FT FOTIO / VISUAL / G-SEAT INTERACTIONS : STUDY 1 2**3 X 3**3 DESIGN - 5984

MANOVA FOR A EMVER GCA • TABLE ENTRIES ARE UNIVARIATE SUMS OF SQUARES.

SOURCE.	CFF	DFF	ERROR
DEPENDENT VARIABLE...DF	2	1	116
8 TT SCORE(1) .	.6179+01	.4850+03	.9061+04
9 TD SCORE(1) .	.8859+0[illegible]	.4695+03	.1523+05
10 ALT(2) .	.679[illegible]+03	.5200+04	.2656+05
11 KIAS(2) .	.5676+01	.2664+01	.1498+03
12 C L DEV(2) .	.15[illegible]+03	.3781+04	.7545+05
13 G P DEV(2) .	.7662+02	.8729+02	.2303+05
14 SMOOTH1(7) .	.1106+0[illegible]	.6543-03	.4465+01
15 SMOOTH1(8) .	.6117-01	.2426+00	.5670+01
16 SMOOTH1(9) .	.6585-02	.3694-01	.1624+01
17 ELEV PWR(1) .	.7727+01	.2860+01	.6061+03
18 AILR PWR(1) .	.3280+01	.1865+02	.1331+03
19 RUDR PWR(1) .	.6565+02	.1546+02	.3613+04
WILKS LAMBDA (WL)..	.9278	.6887	
DF1.................	24.0000	12.0000	
DF2.................	210.0000	105.0000	
FO(APPROX FOR WL)..	.8671	3.9558	
PROB(F>FO).........	.6469	.0009	

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Table 4. **Ceiling/Visibility Main Effects Across Takeoff, GCA, and Overhead Maneuvers**

Source	$\bar{x}$ (clear)	$\bar{x}$ (minimums)	SSBET	SSW/IN	F	p
		Takeoff				
Heading Deviation	3.01	3.77	30.9	642	10.3	.002*
Pitch Deviation	1.79	1.87	.350	116	.646	.423
Course Deviation	1.07	1.15	.388	221	.376	.541
Airspeed Deviation	3.68	6.46	419	3160	28.4	.000*
Elevator Power	2.45	2.65	2.18	113	4.14	.043*
Aileron Power	.720	.847	.873	57.7	3.24	.073
Rudder Power	.430	.411	.018	25.7	.153	.696
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
.840	7	208		.000*		
		GCA				
Total Score	26.9	22.6	1020	25200	8.66	.004*
Touchdown Score	84.9	82.2	390	30700	2.72	.101
Altitude Deviation	40.4	38.8	146	91800	.340	.561
Airspeed Deviation	2.59	2.59	.003	358	.002	.962
Centerline Deviation	95.0	108	9520	277000	7.36	.008*
Glidepath Deviation	34.7	37.2	358	43000	1.78	.184
Elevator Power	.429	469	.087	12.2	1.53	.218
Aileron Power	.464	.464	.003	30.4	.000	.988
Rudder Power	.108	.109	.000	5.16	.000	.986
Elevator Power	4.28	4.11	1.51	1380	.234	.629
Aileron Power	1.54	1.81	3.74	404	1.98	.161
Rudder Power	8.22	8.17	.129	18100	.002	.969
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
.896	12	203		.029*		
		Overhead Pattern				
Pitchout Altitude Deviation	36.3	47.3	6,540	166,000	8.43	.004*
Pitchout Bank Deviation	11.4	9.95	117	6,650	3.75	.054
Elevator Power	1.81	1.97	1.40	364	.823	.365
Aileron Power	.475	.603	.886	41.9	4.52	.035*
Rudder Power	.083	.062	.024	9.78	.524	.469
Downwind Altitude Deviation	35.8	44.6	4,150	119,000	7.43	.007*
Downwind Score	70.4	62.9	3,020	134,000	4.82	.029*
Elevator Power	1.71	2.46	30.2	275	23.47	.000*
Aileron Power	1.07	1.36	4.46	217	4.40	.037*
Rudder Power	.106	.094	.008	7.06	.239	.626
Final Turn Bank Deviation	9.83	11.20	108	5,130	4.49	.035*
Airspeed Deviation	5.07	6.60	126	3,020	8.93	.003*
Elevator Power	1.47	1.79	5.61	272	4.41	.036*
Aileron Power	.745	.870	.852	52.7	3.46	.064
Rudder Power	.515	.328	1.90	117	3.45	.064
Glidepath Deviation	1.09	1.22	927	292	.678	.411
Centerline Deviation	110	154	107,000	13,600,000	1.68	.196
Final Airspeed Deviation	4.23	5.37	70.8	3,340	4.54	.034*
Final Score	12.7	7.87	1,250	77,700	3.45	.064
Elevator Power	2.86	3.18	5.50	555	2.12	.146
Aileron Power	1.77	2.14	7.58	3.49	4.65	.032*
Rudder Power	3.63	4.35	28.4	3,150	1.93	.168
Landing Score	77.1	75.8	87.2	23,700	.786	.376
Wilks Lambda	df_1	df_2		$p(F>F_0)$		
754	23	192		.000*		

Note. — All univariate F's evaluated at $F_{1,214}$.